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THE INSERTION DEVICE MAGNETIC MEASUREMENT FACILITY

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1. INTRODUCTION

The Advanced Photon Source (APS), a 7-GeV positron Storage Ring, will have as many as 34 straight sections available for installation of multiple insertion devices (IDs). Members of the user community have indicated the need to be able to vary the size and the taper of the gap of the IDs to tune the energy of the emitted radiation to their experiments. The IDs must not affect the particle beam motion. Therefore, the APS must ensure that the disturbances are kept within tight tolerances to assure that the ring performance parameters are maintained and that the emitted radiation shows little degradation from an ideal device. Simultaneous tuning of several insertion devices will be allowed and must not affect the ring parameters, other users' experiments, or the emitted radiation outside specified tolerances. Currently, magnetic measurement tests have been performed on a wedge-pole undulator.

Undulator A, a hybrid insertion device using permanent magnets and soft iron pole pieces, will be the first device that will be installed on the APS Storage Ring and the first device to be measured and characterized by the magnetic measurement facility (not including the prototypes). The magnetic moments of the permanent magnets are arranged so as to concentrate the magnetic flux through the pole pieces into the gap between the two magnet arrays. This gives a sinusoidal-like field variation along the length of the device. The wavelength of the harmonic radiation is proportional to the period length of the device and is tuned by opening and closing the magnetic gap, thereby changing the value of the deflection parameter K as seen in Eq. 1.

$$\lambda_1 = \frac{(1 + K^2/2)\lambda_u}{2\gamma^2},$$ (1)

where λ_1 is the wavelength of the first harmonic radiation for on-axis radiation for single particle radiation traversing an undulator with a period length λ_u, and γ is the usual relativistic factor.

2. PURPOSE

The following is a description of the current status of the magnetic measurement facility and is a basic instructional manual for the operation of the facility and its components. Please refer to the appendices for more detailed information about specific components and procedures.

The purpose of the magnetic measurement facility is to take accurate measurements of the magnetic field in the gap of the IDs in order to determine the effect of the ID on the stored particle beam and the emitted radiation. The facility

will also play an important role when evaluating new ideas, novel devices, and in-house prototypes as part of the ongoing research and development program at the APS. The measurements will be performed with both moving search coils and moving Hall probes. The IDs will be evaluated by computer modeling of the emitted radiation (including the emittance of the particle beam) for any given (measured) magnetic field map. The quality of the magnetic field will be described in terms of integrated multipoles for the effect on Storage Ring performance and in terms of the derived trajectories for the emitted radiation. Before being installed on the Storage Ring, every device will be measured and characterized to assure that it is compatible with Storage Ring requirements and radiation specifications. The accuracy that the APS needs to achieve for magnetic measurements will be based on these specifications (see Appendix 1).

3.   FACILITY DESCRIPTION

The magnetic measurement system consists of an accurate positioning system and an accurate magnetic sensor system in a controlled environment for high quality magnetic field measurements. The block diagram in Fig. 1 shows the layout of the bench positioning system with either a Hall probe or a moving search coil attached to the holder of the translation stage. The stepping motors are controlled by the computer through the IEEE 488 interface and the stepping motor drives (Maxwell 1 and 2, and Compumotor). The position of the bench platform is read by the glass scale linear encoders through the Acurite interface. The I/O counter card (CTM05) is used for selecting the step-size between sampled data points. Using the selected step-size, trigger pulses are generated by the "blue box" as the platform moves along the bench z-axis. The Hall probe voltage and the integrated voltage from the moving coil are digitized by a digital multimeter and by an analog-to-digital card (DAS8) in the computer (the DAS8 card is used for on-the-fly display of the data). In the following sections, the bench system is broken down into its components and is described in more detail.

3.1   Bench and Motions

A granite bench purchased from Dover Instrument Corporation, 3.76 m long with a smooth surface of grade AA, is used as the base. Mounted at the top of the base is a granite guide rail used to guide a moving platform. The platform is an air/vacuum bearing that is preloaded against the granite base and guide rail. The air bearing platform (with a travel of 2.90 m) is driven along the insertion device (z direction) by a stainless steel belt drive. The magnetic sensor and various stages are mounted on the platform, which moves the magnetic sensor inside the gap of the IDs. The air bearing platform is driven by a stepping motor controlled by a stepping motor controller.

The magnetic sensor is attached to a holder, mounted on a goniometer (for tilting) that is mounted on a translation stage for movement in the horizontal (x) and vertical (y) directions. The holder may also be rotated by a stepping motor for
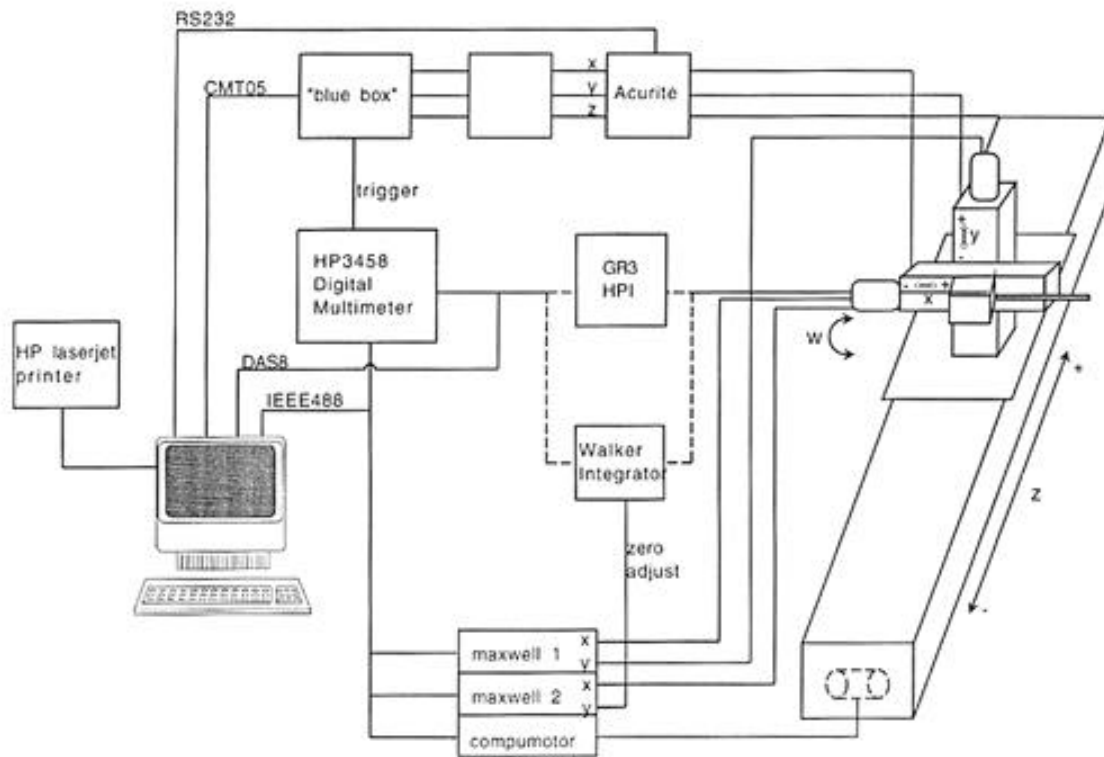
Figure 1.Bench System Block Diagram

alignment purposes (q motion). The motors, motor controllers, and encoders are listed in Table 1.

Table 1. Motion hardware

Axis	Stepping Motor	Stepping Motor Controller	Encoder
z	Compumotor A/AX83	Compumotor 2100 indexer	Acu-Rite III
x	Slo-Syn M062-LS09	Maxwell SMC-202B	Acu-Rite III
y	Slo-Syn M061-LS08	Maxwell SMC-202B	Acu-Rite III
q	From Hüber X	N.A.	N.A.

The bench motions consist of the z-axis, x-axis, y-axis, rotational q-axis, and the tilting motion. The driven z-axis movement is smooth, and high speeds can be achieved (up to 250 mm/s) for quick on-the-fly measurements.   The movements in the x and y directions are performed by fine-thread screws. The tilt motion and rotational motion are not motor controlled. The encoder resolution and maximum speed for each axis motion are given in Table 2.

Table 2. Encoder resolution and maximum speed for the three mutually perpendicular axes

Quantity	x-axis	y-axis	z-axis
Encoder resolution	10 µm	10 µm	5 µm
Maximum speed	50 mm/s	50 mm/s	250 mm/s

The two types of stepping motor systems that control z-axis motion are open loop motions (for on-the-fly measurements) and closed loop motions (for point-by-point measurements). The point-by-point measurements use the feedback from linear encoders that are installed on each axis. The on-the-fly measurement provides much faster data collection (approaching the maximum speed as given in Table 2). However, it also introduces slightly larger positioning errors, which may be compensated for by statistical averaging over several scans. Correct choosing of the integration time and of the number of scan repetitions provides the ability to get the accuracy necessary with on-the-fly measurements.

3.2   Magnetic Sensors

There are two types of magnetic sensors available for the magnetic measurement system: the Hall sensor and the moving search coils.

3.2.1 Hall Probes

The Hall probe measures the magnetic field component perpendicular to the surface of the sensitive area (excluding the planar Hall effect, which involves

measuring other components). Every Hall element is inherently non-linear and temperature sensitive and gives an output voltage that is a non-linear function of both the magnetic field and the temperature. Therefore, each Hall probe must be accurately calibrated at given temperatures to provide a calibration chart of its response to the strength of the magnetic field (see Section 5.1). The measured voltage is then converted to a magnetic field using a fitting function based on this calibration table.

Two Hall probes (model MPT-141) from Group3 are currently used. The Hall probes are miniature sized with a temperature sensor built into the probe head. The probe's overall dimensions are 5 x 14 x 2 mm with a sensitive area of 1 x 0.5 mm encapsulated in epoxy and mounted on a reference surface made of ceramic. A probe is connected to a Hall probe interface (HPI) with a low thermal drift. The Hall probe also has a low thermal drift yielding an overall temperature coefficient of -60 ppm/°C for the complete system. The system bandwidth is 3 kHz and has an inherent noise level of ± 0.05 Gauss when integrating the signal for about 1 second. The noise level increases with decreasing integration time. The results of some of the noise measurements with different integration times are shown in Section 6.2.1, Fig. 6.

Several Hall probe sensors will be investigated and evaluated in the future. The Group3 Hall probes and the Group3 Hall probe interface (HPI) show acceptable performance. However, we expect that the noise level can be reduced, and we will therefore put more effort into this area. The Group3 Hall probe interface has four sensitivity ranges, but the signal-to-noise ratio remains essentially constant; therefore, we have chosen to use the least sensitive range (3.0 Tesla scale for full scale output of 3.0 V).

3.2.2 Search Coils

Two coils have been fabricated, tested, and used in the characterization of the wedge-pole ID. The coil for measuring the magnetic field in the vertical direction has a nominal period length that matches the period length of the wedgepole (3.3 cm).   It has a transverse dimension of 10 mm and has 100 turns. The coil for measuring the field in the horizontal direction has half the transverse dimension of the other coil and has 400 turns to give about the same sensitivity.

To get better accuracy, a third coil has recently been used for vertical magnetic field measurements. It has a length of about 510 mm and is 18 times more sensitive than the coils mentioned previously.

3.3   Controls

Currently, an IBM/PC-compatible computer is used with the control program (written in BASIC) for control of the bench and electronics. The program also controls data acquisition and evaluation. The important hardware components of the control system are listed in Table 3.

Table 3. Control and data acquisition hardware

Device	Model	Function
Compac	386/20	Supervises and controls the data acquisition
Printer	Hewlett Packard LaserJet IIIP	Printing and plotting
IEEE 488	National Instruments IEEE488 Standard I/O card	Parallel communication with I/O devices
RS 232	Serial communication board	Serial communication with I/O devices
DAS-8	Keithley A/D converter	Quick on-the-fly display of measured data
CTM-05	Keithley Multifunction counter-timer board	Counts trigger pulses from z-axis linear encoder. Selects stepsize between data points.
Digital Multimeter	Hewlett Packard model 3458a multimeter	Measures and digitizes analog output of Hall probe. Data is stored internally in memory and recalled and processed at the end of a single pass scan.
Integrator	Walker fluxmeter MF-3D	Integrates the induced voltage signal when using the moving search coil
Scanner	Keithley 705	Scanner for monitoring the temperature sensors. Not yet being used.
Recorder	Yogogawa Hybrid recorder, HR-1300	Records the temperature sensors (up to 8).

3.4   Facility Enclosure and Temperature Control

The facility is enclosed for provision of a clean, temperature-stable, and temperature-uniform environment. The components of the magnetic measurement system and the magnetic moment of the magnetic blocks are temperature sensitive, and the temperature must therefore be kept within very tight tolerances.

The temperature-controlled environment is maintained by means of a forced air system with humidity control and provision for monitoring the barometric pressure. A free-standing room for housing the experimental equipment was built in the Hibay portion of building 362 (see Fig. 2). The room has a clear inside dimension of 15' by 20', and a clear ceiling height of 9' using structural materials with no steel as much as possible.

The HVAC unit is located outside the room and provides a positive pressure to minimize dust entering the room. There are two modes of temperature control for the room: (1) the tight temperature control mode ("test mode" used when making measurements) with the compressor running constantly and with the temperature controlled by a PID-controller, which regulates the silicon controlled rectifiers
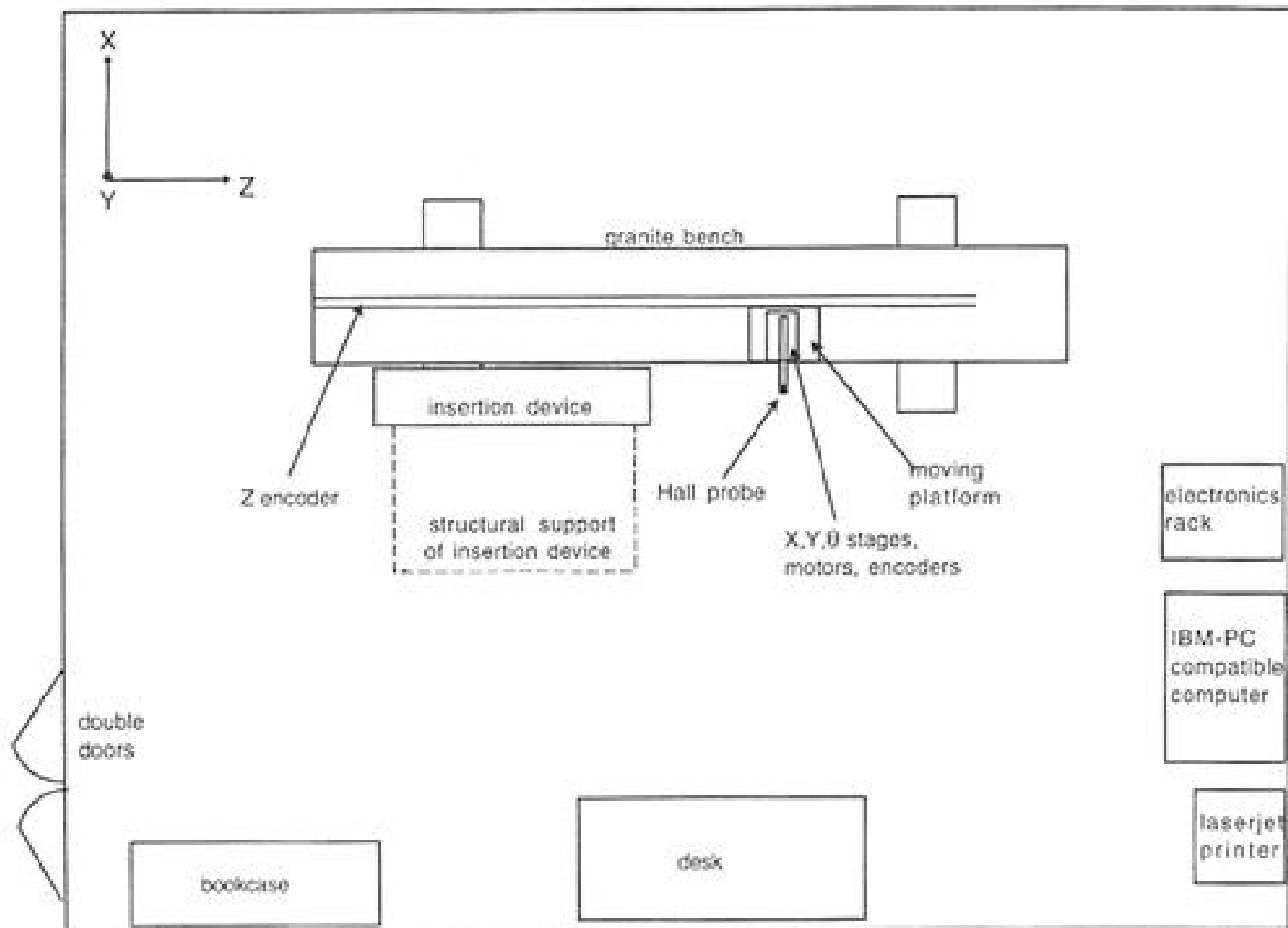
Figure 2. Magnetic Measurement Room Layout

(SCRs) for the reheating system, and (2) course temperature control ("normal mode") with the temperature controlled by a P-controller and the equipment operating as manufactured; i.e., add heat or cooling as needed to maintain the temperature. In the "test mode," we typically achieve a stable air temperature to within 0.2°C during the course of a set of scans (on-the-fly measurements). The HVAC equipment used is summarized in Table 4.

Table 4. HVAC equipment in the magnetic measurement laboratory

Equipment	Description
Liebert Model MME036E	3-ton Evaporator
Liebert Model MMC024A	2-ton Condensing Unit (air-cooled)
SCR with Factory Reheat	Heating Coil 6 kW
Slave Unit *	Second Heating Coil 6 kw
Johnson Controls Metasys LCP Controller	PID Controller
Liebert Controller	P-Controller

*A second heater was added to provide sufficient heating for temperatures above 24°C. Each heating coil provides a temperature increase of about 11°C above the discharge temperature from the cooling coil, which is typically around 11°C.

The supply air is distributed through two wall registers facing the long side of the bench with an airflow rate of approximately 400 cfm and 500 cfm for the two registers, respectively. The return air goes through a single return duct at the short side of the bench, with the control sensor located at the entrance of the duct. The temperature uniformity in the proximity of the bench is better than 1°C.

4.   OPERATION PROCEDURES

4.1   Operating the Bench

4.1.1 Air and Vacuum Procedures

The air supply (from the Hibay) and the vacuum pump must both be on for any platform movement. It does matter which is opened first. The vacuum pump should be pumping on the bearing before the air supply is opened to the bearing. If the air supply is opened first, the platform will pull away from the granite and there won't be a vacuum to pull it back, so the first procedure is to turn on the pump.

There are two valves that need to be opened to pump on the air bearing. First, the switch on the vacuum pump, located outside the room, must be opened (and is normally open). The pump is directly behind the room along the west Hibay

wall and has been enclosed. There is only one switch outside to start pumping. After the switch is turned on, the vacuum valve inside the room, located at the back of the bench near the floor, should be opened completely. After a minute or so, the vacuum pressure gauge should read 20-25 in Hg.

The air supply valves, located both on the bench and outside the room, can now be opened. The valve outside the room should be opened first (and is normally left open). It is located near the windows on the west wall of the Hibay. Next, the air supply valve on the bench, located next to the vacuum valve, should slowly be opened completely. The pressure should read 80-85 psi.

4.1.2 Manual Bench Motions

Manual motions of the bench often come in handy, especially during alignment of magnetic sensors. However, it is important to be careful when moving any of the stages. Damage can result if the stages are moved without regard to whether the magnetic sensor will run into the ID. Manual bench motions are also allowed in the bench control program, but it is usually easier to do this outside of the program.

Any motion of the z-axis platform requires that the air and vacuum be applied to the air bearing. In order to move the platform manually, a friction clutch must be disengaged. The switch for the clutch is located at the back of the bench, near the motor. The platform will move freely when the clutch is disengaged. When moving the platform, care should be taken so that it isn't "slammed" into the limit switches at the ends of the bench. The distance reading is shown on the Acurite z-axis display. The clutch must be engaged again before any computer-controlled movement is allowed. Z-axis motion is also available with the goniometer. This is rarely desired however, because it would change the calibration of the probe to the bench z-axis.

Movements of the x-, y-, q-, and tilt axes can be manually maneuvered whether or not the air or vacuum system is on. Controls for the q rotation and for the tilting motion are on the goniometer. A "key" is inserted in the goniometer and rotated. The q-axis is a rotation about the x-axis. The goniometer tilt is actually two motions. It can tilt around the z-axis and tilt around the y-axis. Manual movement in the y-axis direction can be accomplished in two ways. The goniometer allows y-axis movement, once again by turning a key inserted in the goniometer. Using this form of y-axis motion, there is no change in the Acurite display for y distance. The y-stage can also be moved using the Maxwell stepping motor controller. The Maxwell controller has a toggle switch for y-stage movement, which is labeled as such. Manual movement of the x-stage is accomplished using the same Maxwell controller and is also labeled. When the controller is used, an x-axis and y-axis distance reading are each displayed on the Acurite.

4.2   ID Alignment

Proper alignment of the bench and the insertion device is important. The
alignment procedures involve setting up the bench (once) and aligning the insertion
device to the bench (every device to be tested). The ID alignment is accomplished by
using an optical instrument, a digital dial indicator, and by measuring the field
profile of the device itself. To align an insertion device to the measuring bench, the
following procedure is used.

(1)   Prior to installation, check the vertical alignment of the top and bottom
      magnetic assemblies, viewing the insertion device in the x direction and z
      direction with an optical level. Adjust the magnetic assemblies if necessary.

(2)   Vertically align the probe holder (attached to the moving platform) with the
      optical level over the full travel of the bench. The probe holder should be
      positioned approximately in the nominal center of the device.

(3)   Roughly align the ID to the bench (within 0.002") using a digital dial indicator
      attached to the moving platform and measure along the strong-back of the ID.
      Establish the ID position approximately 0.250" away from the bench.

(4)   Finely align the ID to the bench using the optical level and a modified gauge
      block. The gauge block has a precise vertical line scribed on it and another
      gauge block attached to one end to establish a lip to catch the edge of the pole
      being measured. Perform measurements for the poles at both ends of the
      device.

(5)   Level the lower magnetic assembly to within 2 divisions (0.002") per 12" by
      using a precision bubble level.

(6)   Repeat step 4.

(7)   Repeat step 5 (as needed).

(8)   Check alignment of the probe holder with respect to the poles at both ends
      using the optical level and scribed gauge block.

Changing the gap of the ID is not under computer control at this time. Gauge
blocks are used to set the gap of the ID. The first pole and the last pole are used to
level the gap. With respect to the gauge block technique, the difference in the
height of the first pole and the last pole should be less than .05 mm. The limiting
factor for the accuracy of a gap setting is the vendor specification for the poles. The
specification for the wedge-pole ID is that the height difference between any two
poles is no more than .1 mm.

4.3 Control and Acquisition Equipment

The data acquisition and control equipment is almost completely set up by the bench program. However, it is important to make sure that all of the equipment needed to take Hall probe data or search coil data are turned on.   This equipment includes the computer, printer, Acurite display (which should never be shut off), four motor controllers, HP3458A digital multimeter, Keithly 195A multimeter (to measure the Hall probe temperature), and a self-made adapter for generating trigger pulses.

If Hall probe data are being taken, the Hall probe and it's HPI interface must be connected. If search coil data are being taken, the search coil and the Walker Integrator must be connected. Either the HPI output or the Walker Integrator output is then connected to the HP3458A multimeter. BNC cables from the HPI interface and Walker integrator output are clearly labeled to help with this.

4.4   Data and Analysis Program

Assuming the bench and electronic equipment are set up properly and the ID and sensor are aligned, the data and analysis program can be used. The program is in the directory "c:\apsbench." The program is started by typing "bench." From this point on, there are pull-down menus to help guide you through the program. The program has many options, and this section will only give generalized instructions for a typical scan. For example, doing multiple measurements or searching fiducials to set up the x-, y-, and z-axes are more complicated procedures, refer to Appendix 2 for the entire software manual.

The first display that appears when entering the program is "Bench Control Parameters." At this point, you must choose whether you want to do a scan using the Hall probe or a coil, whether you want to do a point-by-point or on-the-fly measurement, and what scaling is required. If something on this screen needs to be changed, you can Overwrite (type "O") and make any necessary changes. If everything seems to be set up properly, you can Continue (type "C"). The stepping motors are then initialized.

After the initialization, the central menu appears. Typically, the choice at this point is to choose "start a single measurement" under the "measurements" menu. The screen will show a list of the scan parameters as they currently are set. If you want to change something about a scan (i.e., speed, axis limits, whether offset correction is enabled), you need to Overwrite. A screen will again show the current parameters that can be clicked on and changed. Here you can also save the data by giving the file a name. When you are done setting up the parameters the way you want them, you can exit that screen. You will go back to the previous screen and see how the parameters now look. If everything is set correctly, you are ready to start the measurement.

After clicking on "start measurement," the program takes over. It will automatically move to the starting position, according to the set parameters, and

start the scan. The scan can run along the x-, y-, or z-axis. The program can also be set up to do a scan along the z-axis a number of times, move a set distance in the x or y direction, and repeat the z-axis scans. As the data are being collected, the screen will show a graph of the field map and the first and second integrals. This way you can immediately tell if the data looks OK. After a measurement is completed, the data will be graphed on the screen again, this time from the HP3458A multimeter. If the Hall probe linearization is turned on, the graphs are corrected. If multiple scans are being run, the platform will return to its starting position and repeat the same procedure until the entire scan is finished. When the scan is finished, statistical results of the scan are printed out automatically on the laser jet printer. The listed results include first and second integral values, field drift correction, and standard deviations of measurements.

Scan data can be analyzed using a data evaluation program. The program can be used for plotting the scan data and for making evaluations of the data. The program, titled "Auswert," is started from the directory c:\testdat, by typing "\eval\auswert NNN," where NNN is the number of datapoints.   Help with the Auswert program is available from the Help Utility for Data Evaluation Program manual (see Appendix 3).

5.   QUALITY ASSURANCE/QUALITY CONTROL

The quality assurance/quality control (QA/QC) procedures implemented assure that the quantities are measured with sufficient accuracy and that the measurement and evaluation of the insertion devices will be completed according to the proposed time schedule. The major portion of QA/QC for the facility is calibration. The magnetic sensors must be calibrated and checked frequently. For this reason, an in-house calibration system is being built. Currently, probes are sent out for calibration. Other QA/QC measures taken include having spare parts on hand (calibrated Hall probes available), procedures to insure accurate ID alignment (see Section 4.2), and extensive characterization of the bench (see Section 6.1).

5.1   Current Calibration Procedures

The Hall probe system has been independently calibrated by us, the vendor, and an outside laboratory. Calibration data and a fit to the non-linear data was provided by the vendor, Group3. In order to verify the vendor results, Hall probes being used in the magnetic measurement facility were taken to the Synchrotron Radiation Center (SRC) in Wisconsin and the Stanford Linear Accelerator Center (SLAC) in California. The probes were calibrated against an NMR system and the non-linear data were fit to polynomial curves of different orders.

The tests done at SRC used a large electromagnet with a uniform field at the gap mid-plane ($B/B < 1.0^{-5}$ in approximately a 10 mm region). Two Hall probes were brought there to be calibrated. The field was varied from -17 kGauss to +17 kGauss and data were taken from the Hall probe and NMR probe. The data were fit to high order polynomial curves and subtracted from the vendor data polynomial fit. The

curves show a linear deviation with small oscillations (from the fit) superimposed. The maximum deviation between our results and the vendor results is $\pm$7 Gauss and $\pm$ 3 Gauss for the two probes.

The tests done at SLAC also used an electromagnet, an NMR system, and a $\pm$17 kGauss field range. Only one Hall probe was sent to SLAC, the one that had the worse deviation, $\pm$ 7 Gauss. The analysis done at SRC was repeated at SLAC, and the same comparisons were made. The SLAC data fit was subtracted from the SRC data fit. The maximum deviation between the SRC results and the SLAC results is $\pm$ 10 Gauss, see Fig. 3.

Results from all of these tests show that the Hall probes have been calibrated satisfactorily. These tests also gave us experience with calibration systems. We learned that temperature effects are very important (all tests were done at different temperatures). Having a stable calibration temperature (the same as the Storage Ring) is an important consideration.

5.2   In-House Calibration

Procurements are under way for an in-house calibration facility. This is an important addition to the magnetic measurement facility. We will be able to calibrate the magnetic sensors more frequently and will not have to ship them off site. The APS facility will use an electromagnet with 10" poles, replaceable pole pieces, and an adjustable gap. The electromagnet system will be capable of reaching a maximum field of at least 2.3 Tesla. At a gap of 50 mm, the magnetic field will be uniform to 100 ppm in a cylindrical volume 20 mm high by 40 mm in diameter at a field of 1.7 Tesla. We will use a chiller to cool the coils, and the temperature will be monitored. An NMR system will be used to calibrate the Hall probes.

6.   BENCH RESULTS

The bench has been tested in several stages. The first set of tests was characterization of the bench before an ID was present. After the completion of the bench checkout, the wedgepole undulator was aligned to the bench. The wedgepole undulator has been (and is being) tested for an evaluation of the magnetic measurement system and the data analysis package.

6.1   Bench Characterization

The bench and the moving platform were characterized by the vendor before delivery and by us using a laser interferometer after shipment to the APS.   The bench introduces positioning errors of the magnetic sensors due to imperfections in the bench and the moving platform. Therefore, it was vital that the bench and the moving platform were characterized by us and checked against the specifications supplied by the vendor. The laser interferometer was set up on one end of the bench and the appropriate optics were mounted on the moving platform and at the
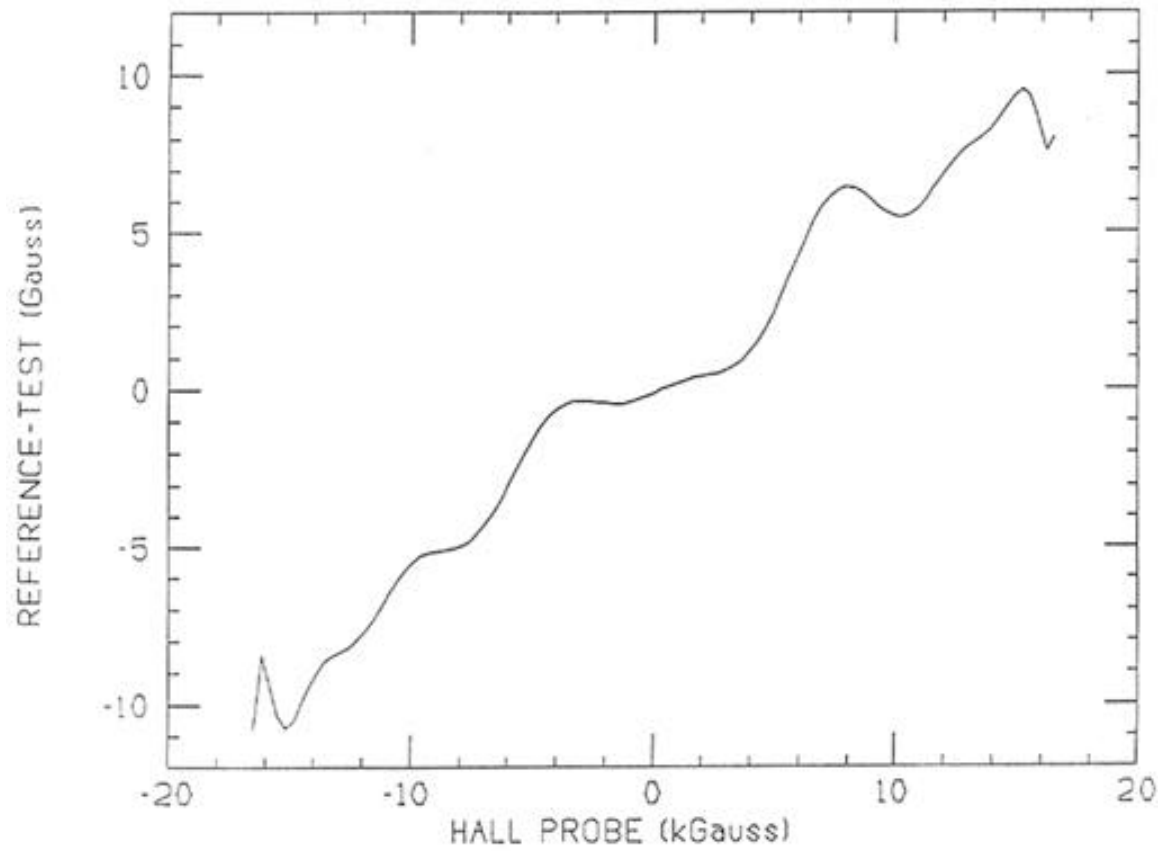
Figure 3. Difference between a 17th Order Polynomial Fit
of the SLAC and the SRC Calibration Data

opposite end of the bench. Tests were done for horizontal and vertical straightness, roll, pitch, and yaw.

The agreement between our data and the vendor data is good except for the horizontal straightness measurements, for which we find a much smaller deviation.The results are compared in Table 5. A schematic of the experimental setup for thestraightness measurements is shown in Fig. 4.

Table 5. Bench characterization

Parameter*	Vendor specifications	Our results
Horizontal straightness	250 µm	20 µm
Vertical straightness	30 µm	30 µm (sags in the center)
Pitch angle	10 arc sec	10 arc sec
Roll angle	10 arc sec	5 arc sec
Yaw angle	10 arc sec	5 arc sec

*Values are listed as maximum deviation from zero when the platform is traveled over the full length of the bench.

The vertical straightness test shows that the bench has a sag in the center where it is not supported. The yaw angle is important and contributes about 5 microns at the position of the magnetic sensor. As an example of the measured data, Fig. 5 compares our yaw angle result with two scans supplied by the vendor. Clearly, there is a good agreement between the measurements. In particular, we find a similar shape in the curves. However, our data are noisier; we suspect the problem was that some of the optical components were mounted on a platform that was not sufficiently secured.

6.2   Performance Evaluation of the Wedge-Pole Undulator

The wedge-pole undulator is a planar insertion device with a period length of 3.3 cm and 25 full strength magnetic poles (it has the same period length as Undulator A). The magnetic field reaches a maximum of 0.7 Tesla at the minimum gap of 11.5 mm.

6.2.1   Hall Probe Measurements

Many magnetic tests were done characterizing the wedge-pole undulator using the miniature Group3 Hall probe and HPI interface. Wedge-pole field maps and first and second integrals of the field map were taken. In analyzing these scans, the accuracy of the Hall probe system was investigated with respect to fulfilling the required specifications.

The main factor that limits the accuracy of the Hall probe measurements is the noise of the HPI Hall probe interface system. The dependence of the

Figure 4. Vertical & Horizontal Straightness Setup
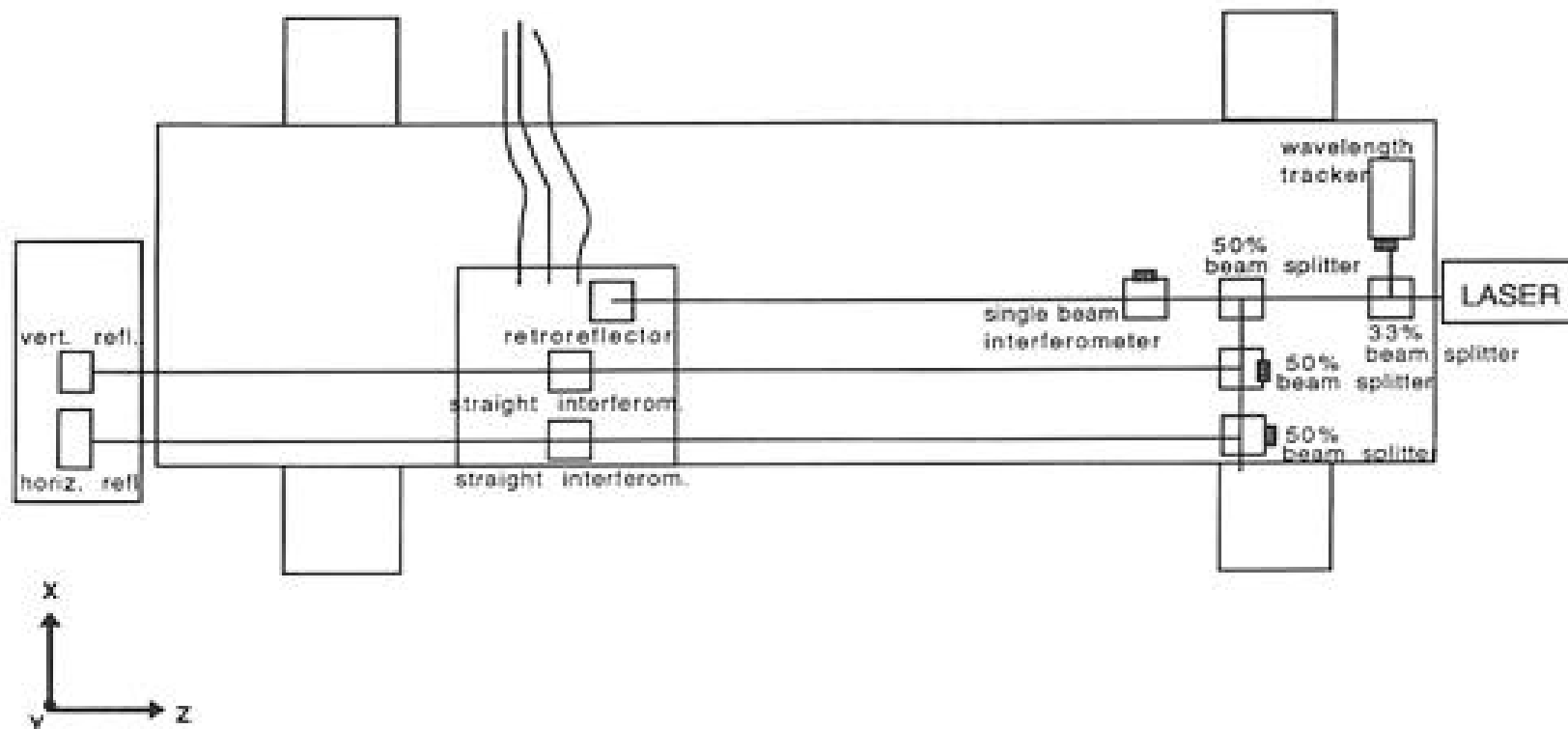
From the plots, the vertical straightness data shows that the platform "sags" in the middle of the bench. The horizontal data shows that the platform bows, away from the trolley side, in the middle of the bench.

" ▬ " denotes a receiver
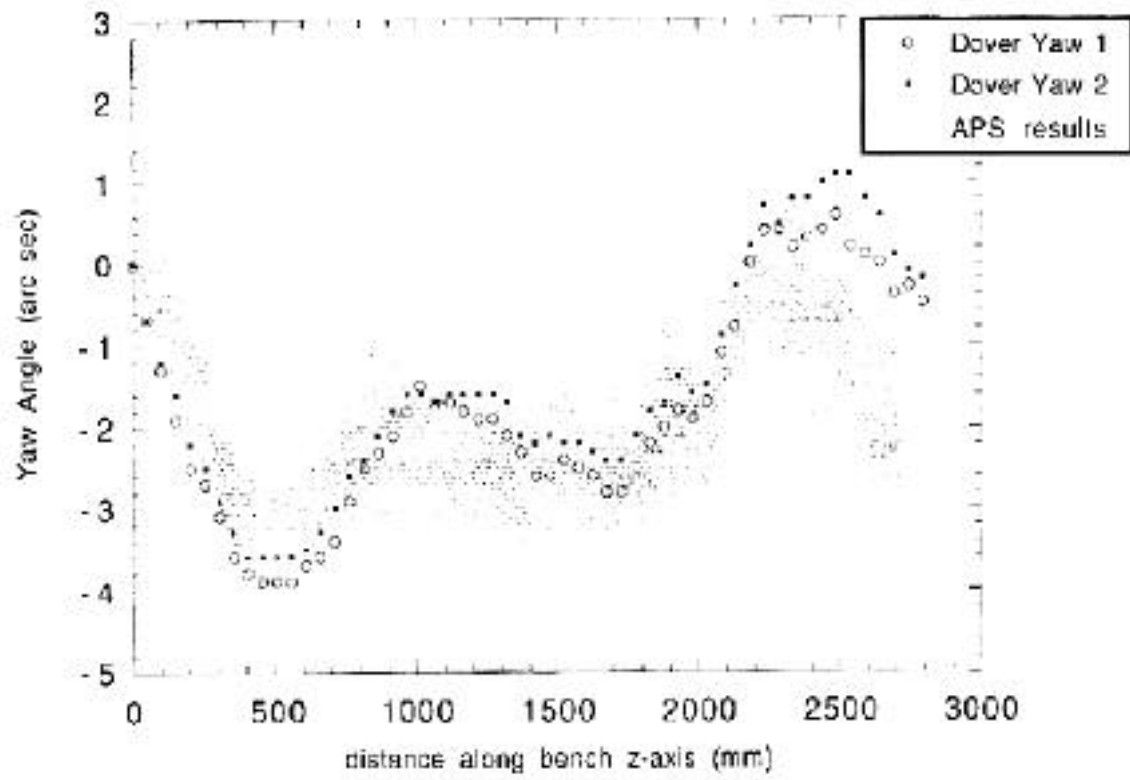
Figure 5. APS and Vendor Comparison for Bench Yaw Angle

integrating time on the Hall probe noise level is shown in Fig. 6 (for platform speeds of 1 mm/s, 3 mm/s, and 15 mm/s). These speeds correspond to integration times of 100 ms, 33 ms, and 7 ms, respectively. For most of the Hall probe measurements, an integration time of 33 ms was chosen as a compromise between measuring time and noise level.

A second important factor in Hall probe measurement accuracy is the temperature instability. Even for the vendor data of .5 Gauss/^{o}C and $\pm$ .5 ^{o}C temperature stability, we have 40 Gauss*cm of error for the first field integral. This is a source of systematic errors in the measurements.

A set of measurements with the Hall probe was performed for estimating the value of the integrated multipole tolerances of the wedge-pole undulator (normal components). For this purpose, we investigated the first vertical field integral dependence on the x-coordinate. The result is shown in Fig. 7 for a 11.5 mm gap. A third order polynomial fit yields the results shown in Table 6 for the normal components of the integrated multipole tolerances.

Table 6. Integrated Multipole Tolerances

Multipole n	Normal Component (b_n)
0 (dipole)	360 Gs*cm
1 (quadrupole)	-1.5 Gs
2 (sextupole)	-5 Gs/cm
3 (octupole)	-43 Gs/cm^2

Only the dipole component does not satisfy the requirements (see Appendix 1 for requirements). Many different techniques were attempted to try to diminish the first and second field integrals and bring them to the desired values. One possible solution is shimming the end poles to zero the first field integral for any gap. But the difference in the first field integrals for all ranges of gaps is rather large, approximately equal to 200 Gauss*cm. A transition to non-symmetrical end poles sufficiently decreases this value. Results of measurements in this case are shown in Table 7.

Table 7. Nonsymmetrical End Pole Results (23.5 periods)

Gap (mm)	J_1(Gauss*cm)	J_2 (Gauss*cm^2)
50	28	-20000
35	26	-18800
28	46	-14360
20	37	-5070
15.5	46	6820
13.5	59	15320
11.5	87	25000

a) platform speed of 1mm/s
   integration time of 100ms
   RMS field = .648 Gauss

b) platform speed of 3mm/s
   integration time of 33ms
   RMS field = .97 Gauss

c) platform speed of 15mm/s
   integration time of 7ms
   RMS field = 2.33 Gauss

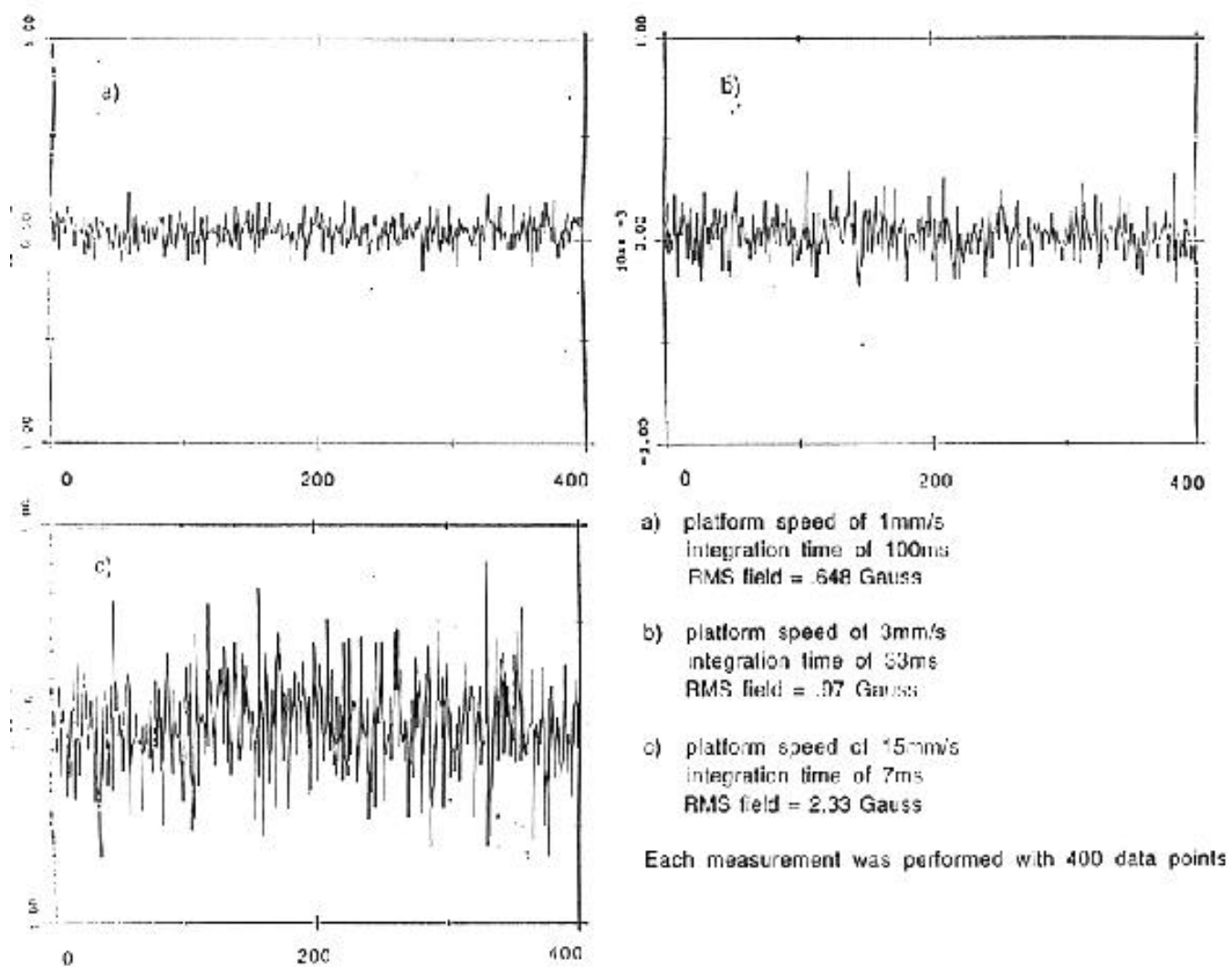Each measurement was performed with 400 data points
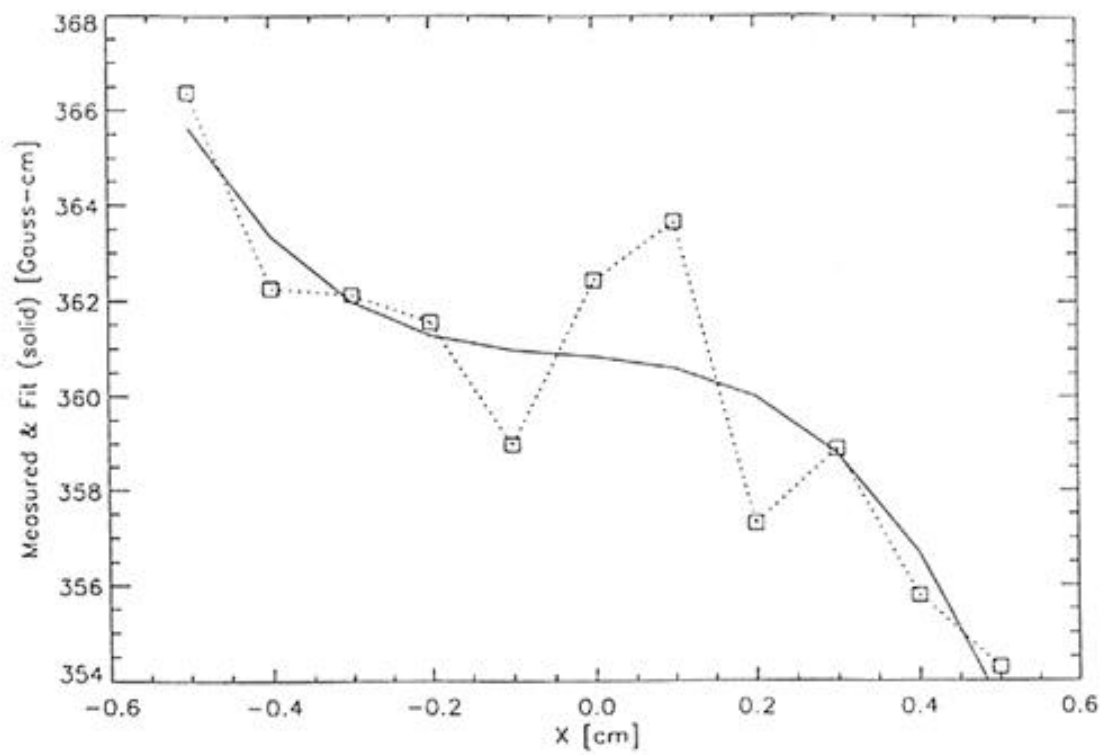
Figure 6. Hall Probe Noise

Figure 7. First Vertical Field Integral vs. X. The graph shows our Hall probe data and a
3rd order polynomial fir for a wedge-pole gap of 11.5 mm.

Results for the first field integral are completely satisfactory. Results for the second field integral, multiplied by a factor of three for the undulator with a length of 2.4 m, gives a value very close to the requirements. The result of the field map measurement for a 15.5 mm gap in nonsymmetrical configuration is shown in Fig. 8. The results of the first and second field integral measurements in the same case are shown in Fig. 9.

The Hall probe results were obtained with RMS statistic errors equal to 3-5 Gauss*cm. The next set of Hall probe measurements will be devoted to measurements of integrated multipole tolerances for different wedge-pole gap settings.

Included here are some general remarks about the wedge-pole Hall probe measurements taken. First, no adjustment nor end pole correction was needed when the gap was changed. During the next set of measurements, accurate measurements of the integrated multipole tolerances in all possible gap ranges should be performed to verify this statement . Also, the measurement results show that, in this case, we do not need end clamps. We have not had any magnetic device placed closer than 300 mm to the undulator, and this is the region where the undulator does not produce any influence on an external device (the scattering field at a distance of 100 mm from the end pole is about 2 Gauss). Moreover, any device situated in this area cannot influence the undulator performance.

The existing accuracy cannot be explained solely by statistical errors and the HPI-produced noise. If it could, the accuracy would improve by increasing the measurement time. But it does not, indicating the existance of some systematic errors. The cause of such errors is not clear and should be investigated. It certainly is not a result of temperature fluctuations, this dependence was too small to produce such values. Field map measurements were performed away from the wedge-pole undulator to separate the effects of Hall probe measurement errors and other reasons. The results are shown in Fig. 10.

6.2.2 Coil Measurements

Three coils were used for the first set of wedge-pole measurements (see Section 3.2.2 for coil descriptions). The two H_Z coils were used for the first vertical field integral measurements, and the H_X coil was used for first horizontal field integral measurements. The H_X coil was also used to study the dependence of the first horizontal field integral on the horizontal coordinate.

A third order polynomial fit yields the results shown in Table 8 and Fig. 11 for the skew components of the integrated multipole tolerances (for an ID gap of 11.5 mm).
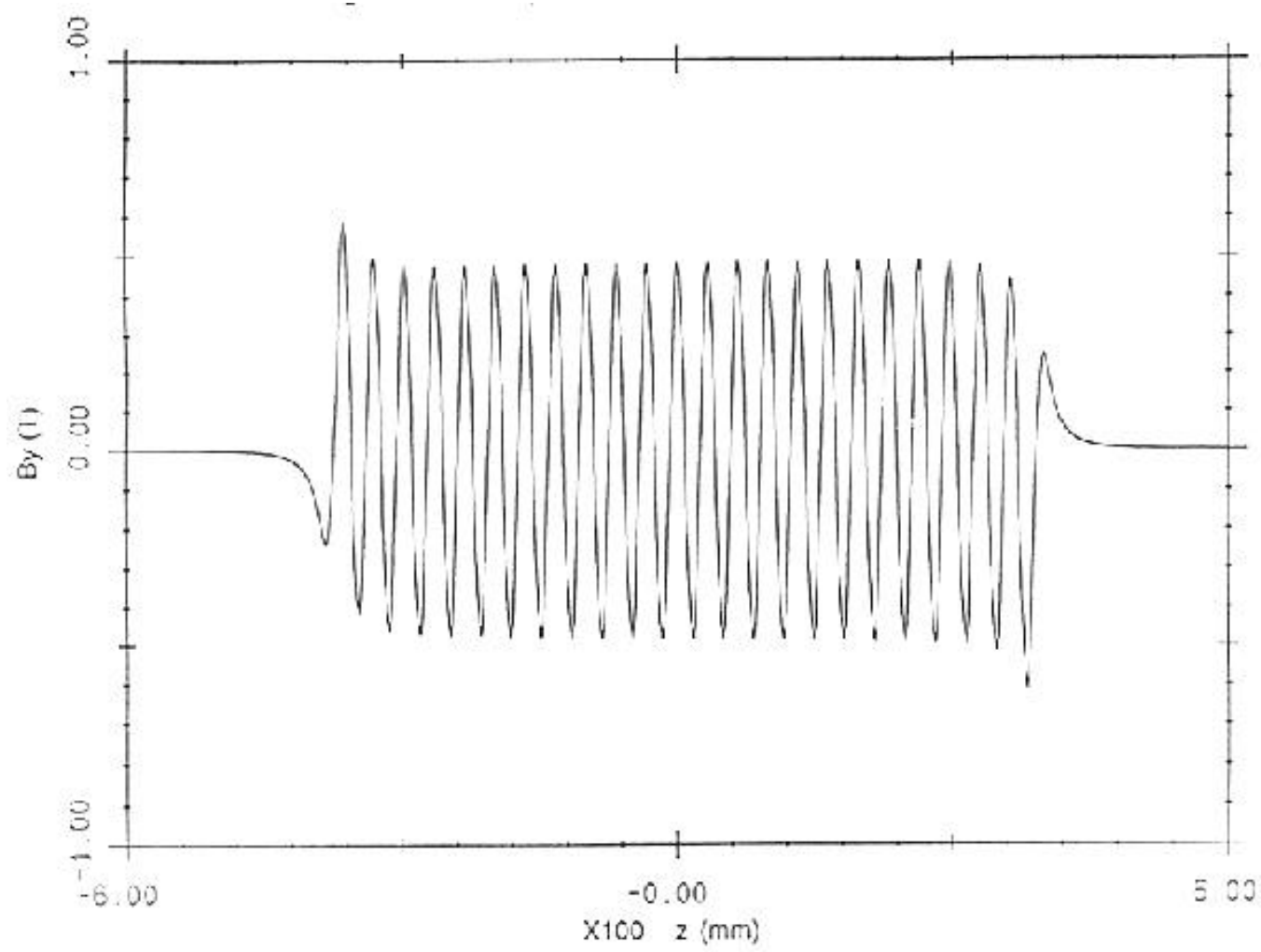
Figure 8. Field Map for Nonsymmetric Configuration, 15.5 mm Gap
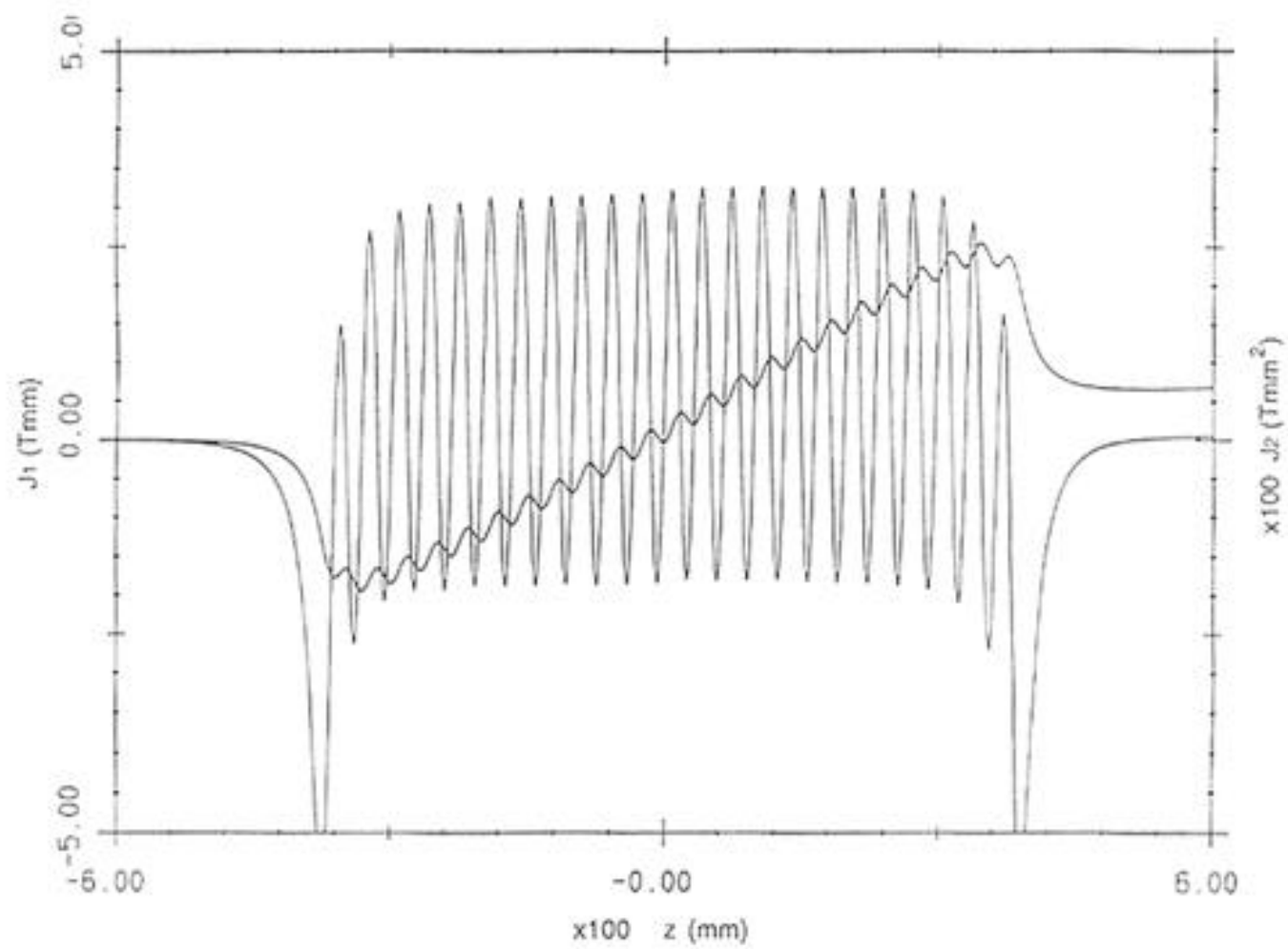
Figure 9. First and Second Field Integral for Nonsymmetric Configuration, 15.5 mm Gap
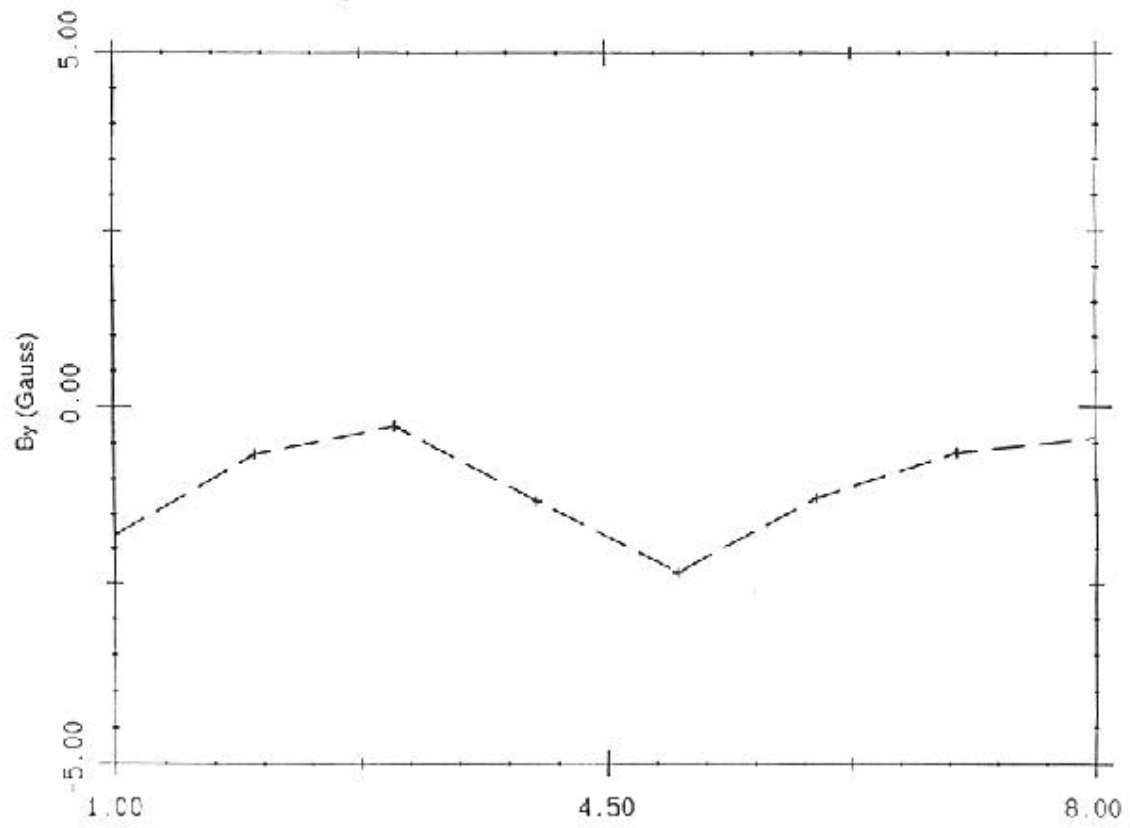
Figure 10. Hall probe zero drift over a period of days
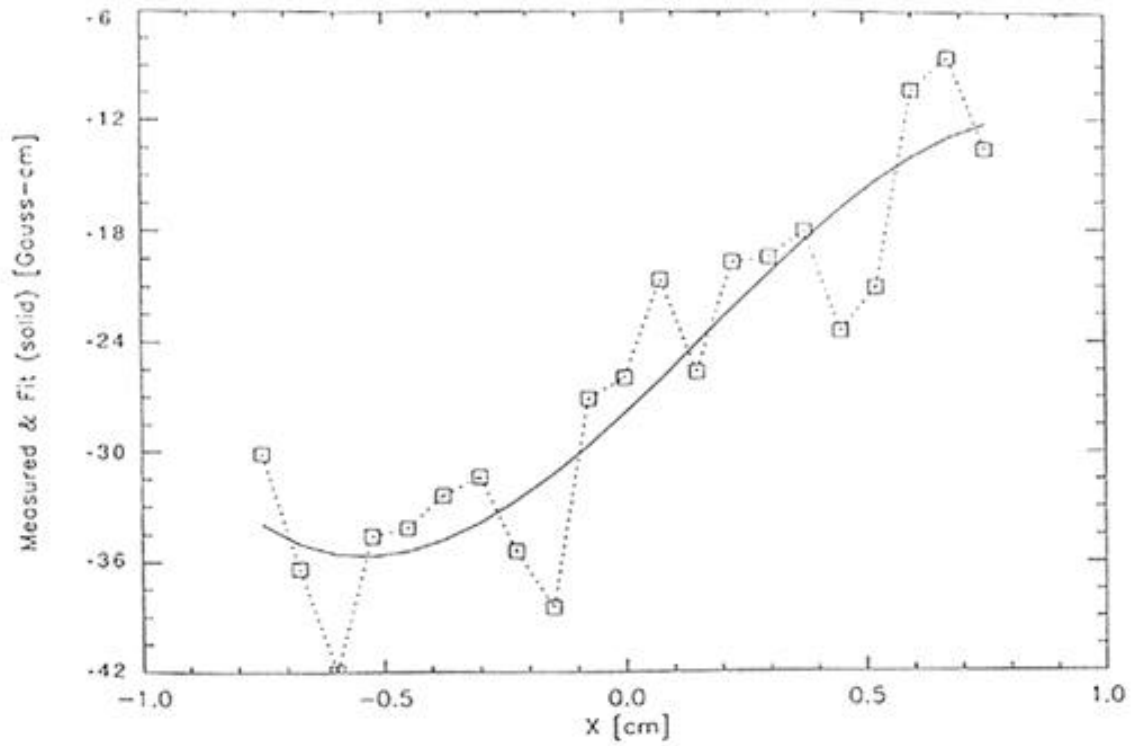
Figure 11. First Horizontal Field Integral vs. X. The graph shows Hx coil data and a 3rd order polynomial fit for a wedge-pole gap of 11.5 mm.

Table 8. Integrated Multipole Tolerances

Multipole n	Skew Component (a_n)
0 (dipole)	-28 Gs*cm
1 (quadrupole)	24 Gs
2 (sextupole)	8.6 Gs/cm
3 (octupole)	-17.2 Gs/cm^2

These results fully satisfy all requirements. Gap dependence will be investigated later.

The wedge-pole first field integral result was obtained with RMS statistical errors, for the 33-mm z-coil, of approximately 10 Gauss*cm. The 510 mm z-coil had been fabricated to get better accuracy, which it did. The error for the x-coil and the error for the 510-mm z-coil were the same, approximately 3 Gauss*cm.

Appendix 1: Accuracy Requirements for Magnetic Measurement

A.1.1 Storage Ring Requirements

Storage Ring and users requirements are derived from stability criteria, which state that the particle beam should be stable within 10% of its emittance. The estimated stability requirements at the straight section of Undulator A are listed in Table A1.

Table A1. Storage Ring beam stability requirements based on a
stable beam to within 10% of its emittance

Horizontal beam size, x	16 µm
Horizontal beam divergence, x	1.2 µrad
Vertical beam size, y	4.4 µm
Vertical beam divergence, y	0.45 µrad

The stability requirements can be translated into requirements for the integrated dipole fields (integrated over the length of the device including the fringe field region) at any point within the so-called good field-region of ± 5 mm horizontally (x) and ± 2 mm vertically (y), at any gap or tapering of the gap (see Table A2).

Table A2. Integrated dipole requirements derived from beam stability criteria

Quantity*	Vertical Field	Horizontal Field
1st field integral	26.5 Gauss*cm	11.2 Gauss*cm
2nd field integral	37,400 Gauss*cm²	11,200 Gauss*cm²

*The integrals are defined as

$$I_{x,y}(\ell) = \int_{-}^{\ell} B_{x,y}(z)\,dz, \; J_{x,y}(\ell) = \int_{-}^{\ell} I_{x,y}(z')\,dz'$$

for the first and second field integral, respectively.

These tight requirements cannot be met without using closed loop orbit compensation, and, with those systems installed, it is reasonable to relax the requirements a factor of ten or so, arriving at the relaxed requirements listed in Table A3. Active end-correctors of the insertion devices for adjusting the integrated fields with a resolution of 10 Gauss*cm, or better, will assure that those tolerances are met. Thus, it is proposed that the magnetic measurement system be able to measure the integrated dipoles with an accuracy on the order of 10 Gauss*cm and 10,000 Gauss*cm², for the first integrals and second integrals, respectively.

Table A3. Integrated dipole requirements when using steering compensation

Quantity[*]	Vertical Field	Horizontal Field
1st Integral	100 Gauss*cm	50 Gauss*cm
2nd Integral	100,000 Gauss*cm^2	100,000 Gauss*cm^2

[*]End-correctors of the insertion device are installed. The requirements must be met for all gaps with a single setting of the end-correctors.

These requirements also put restrictions on the allowable integrated multipoles in the good field region for the insertion devices as summarized in Table A4.

Table A4. Integrated Multipole Tolerances

Multipole n	Normal Component (b_n)	Skew Component (a_n)
1 (Quadrupole)	50 Gauss	50 Gauss
2 (Sextupole)	200 Gauss/cm	100 Gauss/cm
3 (Octupole)	300 Gauss/cm^2	50 Gauss/cm^2

The definition of the integrated multipoles used here is given by

$$(B_y+iB_x)dz = \sum_{n=0} (b_n+ia_n)(x+iy)^n ,$$

where the integration in the z direction must extend well beyond the ends of the insertion device into the region where the field from the insertion device is negligible. For Undulator A (2.4 m long), this would involve taking data over the range ± 1.4 m with respect to the center of the device.

A.1.2 Spectral Requirements

The spectral requirements of the insertion devices are set by the requirement that the brilliance of the third harmonic radiation must not be less than 70% of an ideal device for any magnetic gap. For Undulator A, this requirement imposes the following requirements on other derived quantities:

• In the periodic magnetic field, excluding the ends, the averaged beam trajectory (i.e., averaged over each period to eliminate the periodic component) must be straight within ± 2 μm in both the x and y directions, and the angular excursions of this averaged trajectory must be less than 5 μrad.

• The optical phase error in the periodic magnetic structure (excluding the ends) must be less than 8 degrees in the non-tapered configuration.

A.1.3 Error Analysis

We have started to perform error analysis of the effect of statistical errors and experimental errors on calculated quantities, in particular, the first and second field integrals. In the simplest case, considering only random errors normally distributed with zero mean and standard deviation , the first integral is essentially a summation of all data points, and the standard deviation for the value of the first integral is $\sqrt{N}$ z , where N is the number of data points, and z is the step size in the z direction. Expressed differently, L=N z. The error then becomes $\dfrac{L}{\sqrt{N}}$. For a 3-m-long device using 10,000 data points, a standard deviation of 3   is obtained, which is 3 Gauss*cm if   is 1 Gauss, which is our goal.

Introduction of more complicated errors is most easily simulated on a computer. For example, if the errors arise from positioning errors of the moving platform, then the standard deviations would not be all the same, and the effect on the integrals are not easily predictable. Combination of errors is also possible using computer simulations.

Appendix 2: Description and Documentation of the Bench Control Program

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PRINCIPLE DESCRIPTION

The program BENCH is an adapted version of the bench control program MESSUNG, a multipurpose control program for magnetic measurements of Insertion Devices (IDs) used and developed at HASYLAB. BENCH contains basically the same features as the original with some limitations set only by the hardware found at the APS bench. The program itself is modularly structured and will be described in detail in this documentation. Its basic features are:

1. Hall probe measurements can be made in both fast "on-the-fly" and slow and low noise "point-by-point" modes. Hall probes for either horizontal or vertical field measurements may be used. Adjustment, especially for the horizontal field probes, is greatly simplified by the HUBER goniometer head used.

2. Measurements using suitable coils together with an analog WALKER integrator can be performed as well. The drift of the integrator is adjusted by a small stepping motor. Automated measurements that need no operator assistance can be made. Providing that suitable coils are available, these techniques can be used in the horizontal and vertical directions as well using the same HUBER probe mounting as in the case of the Hall probe. Because drift is always present in integrators, only fast on-the-fly measurements make sense. Any number of scans (field maps), that is, field values measured in constant step sizes along a selectable direction (x, y, or z), can be recorded and stored. For each scan, parameters that depend on direction like x-, y-, or z-offsets, or (later when the suitable hardware is installed) the probe rotation angle, w, as well as the gap value of an insertion device can be adjusted. This will be referred to as "FIELDMAPS" throughout this documentation. Only the results of a scan, namely the first and second field integrals, are determined after a scan and stored for later processing (determination of multipole coefficients, etc.). This mode will be called "FIELDINTEGRALS." FIELDMAPS as well as FIELDINTEGRALS can be made using a scheme for correcting Hall probe non-linearities with suitable calibration data, which of course must be provided to the program. A special feature allows for programming any number of measurements that will then be executed one after the other. The coordinate system used has the x and y directions as the transverse horizontal and vertical, respectively, and the z direction as the longitudinal. An ACURITE system using an incremental glass scale encoder is used for position measurements. As with numerical machines, absolute coordinate values can be located using the fiducial trigger marks (FTMs) of these scales. In this way, an absolute scale with an arbitrary coordinate origin can be chosen and re-established at any time by the program. Additional utilities include:

1. the hand control mode, which enables "manual" bench movement using the computer keyboard,
2. display, printout, and test of the Hall probe calibration data,

3. the ability to zero the field offset of the Hall probe using a zero Gauss chamber,
4. display of initialization data for the measuring system and the stepping motors,
5. display of all addresses used at the AT bus and the IEEE 488 bus,
6. a simple test routine for IEEE 488 devices.

Hardware Required for the APS Version

Fig. A1 shows the basic functional principle of the magnetic bench and its controls, connections, and wiring. Its main components are:

1. An AT-386 Computer with the following hardware installed:
   a) Serial RS 232 interface
   b) Parallel interface
   c) National Instruments IEEE 488 interface
   d) Keithley/Metrabyte DAS8PGA analog to digital converter card
   e) Keithley/Metrabyte CTM05 multipurpose counter card
   f) About 4 MB of memory is more than sufficient.
2. An ACURITE III three axes coordinate measuring system with an RS 232 interface. Glasscales are mounted on all three coordinate axes. Absolute coordinates can be obtained using the FTMs.
3. A Compumotor 2100 indexer with an IEEE 488 interface and microstepping driver to control the long z-axis.
4. A Maxwell SMC-202 C two-axis system with an IEEE 488 interface to control the x and y motions of the bench.
5. A second Maxwell SMC-202 C system with IEEE 488 interface to control the zero drift adjustment of the WALKER integrator and the Hall probe/coil rotation.
6. A Hewlett-Packard HP3458A digitizing multimeter that is used to record the spectra. It is also equipped with an IEEE 488 interface.
7. A self made adapter circuit in a Keithley STA-U screw terminal box (blue box) using opto-couplers, which is needed to generate the trigger pulses for measurements for the HP3458A
8. A Keithley 195A multimeter with an IEEE 488 interface to measure the Hall probe temperature.
9. A HP Laserjet III printer with parallel interface for alphanumeric and graphic output.

RUNNING THE PROGRAM

The program code is stored in the directory C:\APSBENCH. This directory also contains the source code of all modules and also includes files, bench control files, and linearization data files for one Hall probe. The program is started by typing "BENCH." A box displays the latest update of the program at this point. First, the STARTUP program is executed, (refer to STARTUP later in this text). After successful STARTUP, the central menu is displayed. There are three pull-down menus titled "Measurements," "Utilities," and "Display." As in many MICROSOFT programs, the pull-down menus can be activated by using the mouse or the ALT key together with the highlighted character. In addition, many (not all) menu items can also be activated using the F-keys. There is a display of F-key assignments available on the screen. Important: Cntl X exits the program. From this central
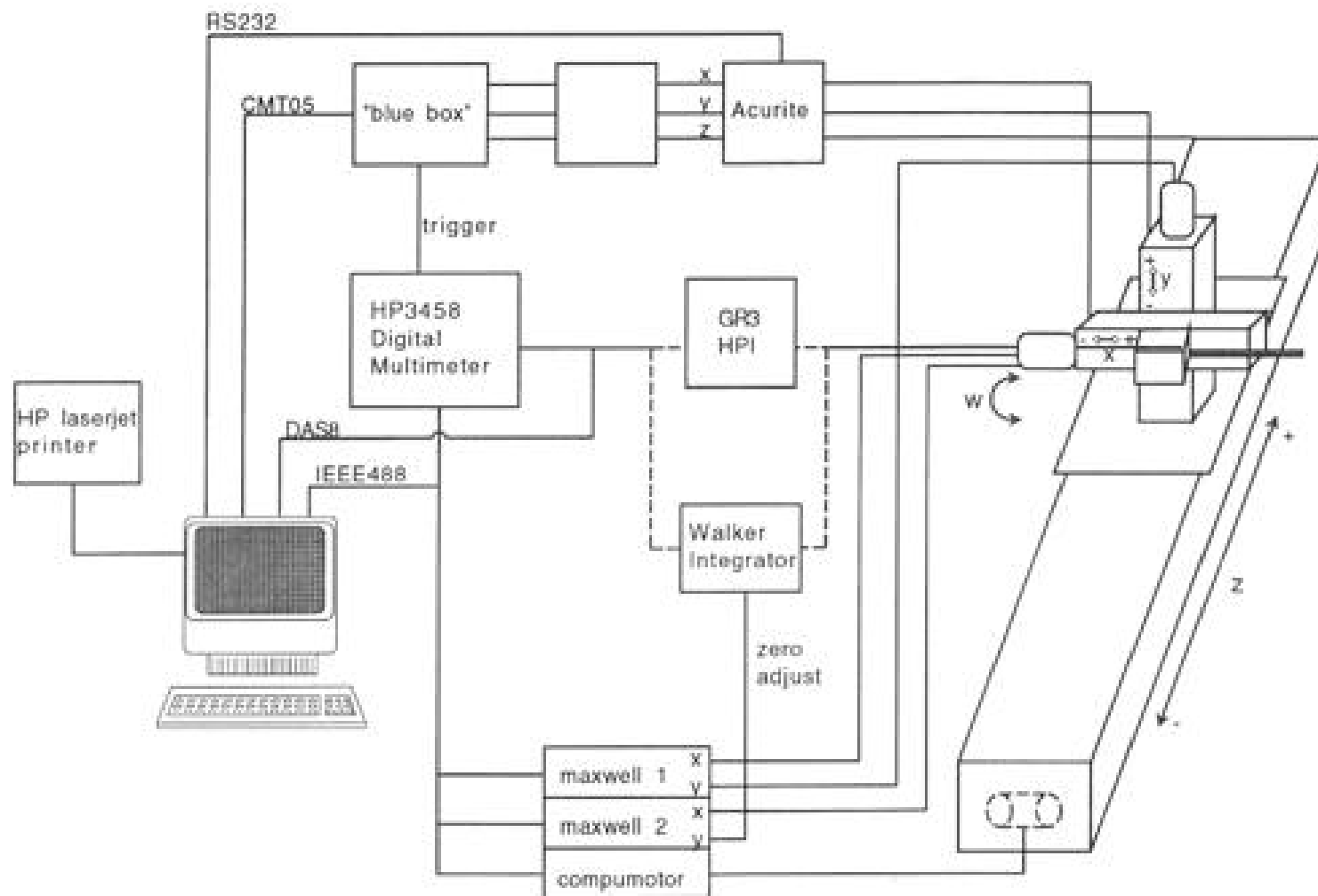
Figure A1. Bench System Block Diagram

menu, one can choose from three menus:

Measurements:
  1 -- Start a single measurement
  2 -- Program a sequence of measurements
  3 -- Start a preprogrammed sequence of measurements
  4 -- Run STARTUP again

Utilities:
  5 -- Push to DOS
  9 -- Long-term observation of Hall probe output (drift)
 10 -- Simple test routine for IEEE 488 devices

Status:
  6 -- Display status of limit switches, vacuum, and pressure control
  7 -- Display, print, and test Hall probe linearization data
  8 -- Display AT and IEEE 488 addresses in use, display last program changes
 11 -- Exit the program

Items 1-5 and 11 are frequently used for measurements; whereas items 6-10 are for test and diagnosis only. These items will be described in detail below.

Detailed Description of Program Items

STARTUP

This is a central program module that controls and sets all parameters of global interest, that is, those that need not be changed for every scan, such as bench control files, Hall probe range, display scaling, or display colors. Each time the STARTUP routine is run the following steps are executed:

 1. The STARTUP parameter file (SPF) is read from the current directory. On each new start, the default name "Messbank.par" is assumed, but other files can be used as well. In the SPF, the STARTUP parameters of previous runs are stored. If they do not exist, default values for all parameters and file names are assumed. In that case, a warning message is displayed and care should be taken. The content of this file is displayed on screen. There are several options available:

    -- The parameters may be changed, O(verwrite)
    -- These parameters may be stored on a file or on the default file
       "MESSBANK.PAR," W(rite to Disk)
    -- Parameters from SPF may be read in, R(ead from disk)
    -- The actual parameters may be printed on the printer, P(rint)
    -- Standard values may be set, S(tandard)
    -- Continue program execution, C(ontinue)

    The SPF contains the file names for the bus address file, the initialization file for the stepper motors and coordinate measurement system, and the file containing the Hall probe linearization data. These three files are referred to as

BENCHCONTROLFILES. When you want to change the SPF, choose overwrite and enter a simple change routine. You are asked in this order: Change BENCHCONTROLFILES (Y)ACPCinUSE.

<u>Functional Description of Modules and Subroutines Contained Therein</u>

The program is subdivided into a number of modules that on one side allow for modular program development and are also essential for an overlaid program code. A module is an independent program unit that contains one or more subroutines. The following section gives first an alphabetical listing of the modules and the subroutines contained therein together with a brief functional description. Then an alphabetical listing of all subroutines is given. To avoid confusion: in some modules, subroutines contain the same name as the modules names. The program uses a number of files that are essential for operation. The names of these files are stored in variables having easy mnemonic names:

BusadressFile$: This file contains the addresses of AT bus cards, the printer status register,and the GPIB addresses of all devices needed.

PhytronIniFile$: This file (name is a relict from Hamburg) contains the offsets of the axes of the ACURITE system with respect to the FTMs, the line spacings of the glasscales used, and all data needed to initialize and set the Compumotor and the two Maxwell stepper motor drives.

HallProbeFilename: This file contains data needed for Hall probe linearization. Two different methods can be used: spline fitting of the measured data or polynomial approximation of order up to 20. Other data in the file correspond to probe identification, the last calibration date, and the field range for which the calibration is valid.

MODULES:

ACUINI: Programs for the initialization of the ACURITE encoder system.

 Acuini
   Main subroutine controlling ACURITE initialization and zero shift of the coordinate system.

 PhyIniOverwrite
   Overwrites the old offsets on the PhyIniFile$

 PhyRef
   Shifts the zero of one or more axes (shift zero) or initializes the counters of one or more axes of the ACURITE system using the FTMs of the glass scales (search fiducial marks).

BENCH: Module containing the main program and some utilities as well. The main program calls the subroutines that perform further actions.

 AnfangsText
   Display the message box in the program with the information of the latest updates.

 HallDrift
   Measures the voltage of the Hall probe system using the HP3458A. Needed by the subroutine "TIMEDEPENDENCE."

 HallKorrDisplay
   Displays the data used for Hall probe linearization, but only if it is enabled in the STARTUP subroutine (HallprobeLinearityControl% =1). The contents of the filename in HallprobFileName$ are displayed or can be printed out. A special test routine seeing the effect of Hall probe linearization is also provided. It can be used to check a new data file with linearization data. The uncorrected Hall voltage as would be measured by the system can be typed in. The corrected Hall voltage, the 'true' field and the correction to the measured field are displayed. These numbers can be checked with the measured calibration values.

 InfoText
   Displays the F-key assignments on the screen.

 SetupMenue
   Sets up the menu, the menu text bars, activation keys, and some of the F-keys.

 TimeDependence
   Allows a high resolution observation of the drift of the Hall probe system. Uses the subroutine HALLDRIFT to measure the drift in selectable intervals. Data are stored on a file that always is named "DRIFT.DAT". It is written in the format of the program and can be read in with the data evaluation package.

DEFADD: Contains the programs for defining the addresses and gives their status.

 Adressinfo
   Displays the content of the BusadressFile$ on screen.

 Defadd
   Reads the Busadressfile$, which contains all addresses of cards used in the AT Bus CTM05, DAS8PGA (PIO24 is not used here), the address of the printer status register, and all the addresses used (and some more) of the GPIB devices used.

DAS8MESS: Subroutines for measurement using the DAS8PGA board for control as well as the HP3458A in direct mode, Hall probe linearity correction, Hall probe temperature measurement, correction of the zero drift of the Hall probe, and a routine for quadratic interpolation.

Das8Messung
  Performs measurements depending on the measurements MODE stored in
  ACPCinUse% to be set in the STARTUP subroutine.

  ACPCinUse =0: measurements of up to three channels, CH0 through CH3, using
  the DAS8PGA board can be made directly if ACPCinUse% =0 and the
  corresponding channels are chosen. Measurements have 12 bit resolution. Only
  CH1 is connected, it is not recommended to use this mode for measurements.

  ACPCinUse% =-1: measurements are made using the HP3458A multimeter
  directly in fast mode, 60 measurements per second if on-the-fly is set ON. If set
  OFF (point-by-point mode), then high resolution measurement mode is switched
  on and one measurement takes about 300 ms.

  ACPCinUse% =1,2,3: DAS8PGA performs measurements on channel 1, which is
  used for control purposes only.

HallKorr
  This function corrects the voltage read by any source on channel 1 (depending on
  the mode) and returns the corrected Hall probe voltage. The scaling set in the
  STARTUP subroutine is properly taken into account. To perform the correction,
  the linearity control must be switched ON (Hallprobelinearitycontrol%=1) and
  the Hall voltage must be in the range valid for the Hall probe used. Linearization
  data are provided by reading the file HallProbFileName$ read by the
  READHALLPROBEKORREKTUR subroutine in the STARTUP Module. If the
  linearity correction is switched OFF or is too large for the calibration range, the
  Hall voltage is not corrected and is returned unchanged. See subroutine
  'READHALLPROBEKORREKTUR' for more details.

HallProbTemperature
  This subroutine determines the temperature of the Group3 HPI probe using the
  Keithley multimeter.

Inpol
  This function performs a quadratic interpolation through three points, needed to
  determine the Hall probe temperature in Centigrade from the voltage measured.

ERRCHECK: This module contains a subroutine for GPIB error treatment and one
for checking if a file already exists.

  CheckFileExistence
  Checks if a file name already exists. Caution, avoid overwriting existing files.

  Gpiberr
  Provides an analysis if errors on the GPIB bus occur using the NI-488.2 GPIB
  driver package. It analyzes errors encountered during GPIB operations and gives
  corresponding error messages.

HAND: Program to move the bench manually by pushing keys on the keyboard.

   HandXYZW
   Enables hand controlled bench motion. With the existing stepper motor drives
   (Maxwell), it is of limited use because no continuous motion and stop commands
   exist. Also the w-axis is not enabled for this purpose.

HP3458ST: Subroutines needed to use the HP3458A multimeter in fast digitizing
mode, ACPCinUse% 1,2,3, and to provide the pulses needed for synchronization.

   CTMRead
   Reads counter 5 of the CTM05 board, which counts down the incoming pulses.
   Can be used to determine residual pulses.

   CTMSetup
   Selects the appropriate source for synchronization pulses on the CTM05 board
   depending on the scan direction and directs it to the counter 5. Counter 5 is
   configured to "Count Down," "Count Repetitively," and "Terminal Count Pulse" if
   the counter content is counted down to zero. The counter 5 register is preloaded
   with a number depending on the encoder line distance of the axis selected and
   the chosen step size for the measurements.

   Teilerset
   Calculates the numbers needed to load the counter 5 register of the CTM05
   according to scan step size and the encoder pulse distance. Needed by
CTMSetup.

   HP3458Setup
   Controls the proper input selection for synchronization pulses using the
   CTMSetup subroutine. Sets up the HP3458A for fast measurements. Sets the
   integration time of the multimeter according to selected measurement speed and,
   finally, arms the trigger input for measurements.

   HP3458Stop
   Disarms the HP3458A trigger input. Reads the actual number of readings and
   the scale factor.

   HP3458Store
   Reads the readings out of the memory of the HP3458; writes it to a virtual disk
   file; displays the field and the first and second field integral, if wanted.

MAPMESS: Provides the appropriate environment to perform measurements

   LinReg
   Performs a linear regression and error analysis. It is needed by subroutine
   "MAPMESSUNG."

MapMessung
The central subroutine that controls the measurements to be performed.
Depending on the parameters, field maps in chosen directions or field integral
scans can be performed as functions of numerous parameters by calling the
"SCAN" subroutine. Data storage is managed by calling the subroutine
"STOREONDISK."

MessReihe
Controls the execution of a "Messreihe," a series of measurements that must
have been previously programmed. "MESSREIHE" reads the measurement
parameters from the file "MESSFILE.PAR" and uses "MAPMESSUNG" to
perform the measurement.

RMS
Calculates the average and the root mean square of an array. It is needed by the
subroutine "MAPMESSUNG."

MAPPARA: Editor for measurement parameters using the QBX user interface,
toolbox mouse menu, and window subroutines.

ChooseKind
Makes the first selection of the menu. There are two alternatives, field map or
field integral. Field maps can be selected to run along the x, y, or z directions.
Field integrals can be made as a function of: the horizontal (x) or vertical (y)
offset, a circle in the x-y plane, the gap and the probe rotation angle w (not
available yet). Choices are clicked with the mouse. "CHOOSEKIND" is finished
by clicking <continue> and the parameters appear for the measurement type
selected.

EditParameter
Editor for the parameters. It is activated by clicking the parameter box.
Parameters in this sense are all quantities that are not directly connected with
the scan motion. To change scan parameters, see "EDITSCAN."

EditScan
Editor for the scan parameters such as scan start-endpoint, step size, speed,
direction (if a field map scan), or offset correction. Other parameters are selected
in the parameter box.

EditStore
Editor for data storage and protocol HauptMenue central menu, which controls
the activation of the three edit subroutines above.

MapParaMeter
Displays measurement parameters. If chosen, it activates "CHOOSEKIND" and
the edit subroutines to change the parameters and then stores them on a disk.
"MAPPARAMETER" can also be used to program a series of measurements.

MapParaPrint
Displays parameters of a measuremnt on the screen.

StoreBack
After a manipulation is performed ("CHOOSEKIND," "EDITPARAMETER,"
"EDITSCAN," or "EDITSTORE"), Storeback stores the parameters back into the
variables used in the program.

TextMapEingabe
Opposite function of "STOREBACK." Program variables to be changed by
"CHOOSEKIND," "EDITPARAMETER," "EDITSCAN," or "EDITSTORE" are
stored into variables that are changed in these subroutines.

MoniPlot: Subroutines used to display graphics on the screen. To use these
subroutines, the color information contained in the common shared variables listed
below must be previously set. Setting the color information in the program is done
in the STARTUP subroutine. Changes are made using SETCOLOUR.

FarbeHinterGrund%   (background color)
FarbeRand%   (color of frame)
FarbeKurve1%   (color of curve 1)
FarbeKurve2%   (color of curve 2)
FarbeKurve3%   (color of curve 3)

DisplayLine
Plots a line between two points onto the screen. Clips lines that have start or
endpoints outside the screen. Up to three different lines in different colors can be
plotted. To plot up to three lines :
  1. Assign a color value > -1 and < 15, -1 switches the curve off.
  2. Assign plot limits to the following common shared variables:
      Ydisplaymin1 YdisplayMax1
      Ydisplaymin2 YdisplayMax2
      Ydisplaymin3 YdisplayMax3
    In this way, different scaling can be used in one plot.

DisplayPoint
Plots a point onto the screen. Up to three different colors and scalings can be
used, see DISPLAYLINE.

FrameD
Draws a coordinate system

MOTOR: A package of hardware-specific subroutines for stepper motor operation.
This is the only module that contains device-specific motor commands.

MotorControl
Allows for motion of the five stepper motor axes:

x, y, z   for Bench movement
u   for drift control of the Walker Integrator
w   for probe rotation.
Identical commands are possible on the x-, y-, and z-axes, which are ACURITE
equipped, including absolute positioning.   There are a limited set of commands
for the u- and w-axes.

OpenCloseACURITE
Controls the proper opening and closing of the serial RS 232 interface on file #39
for the ACURITE system.

PresetACURITE
Performs special procedures needed to preset the ACURITE system to desired
values and to auto-enable (for the search of FTMs). It is needed by "ACUINI."

ReadACURITE
Reads out the position value of the three directions: x, y, or z.

StepMotorsIni
Reads the PhytronIniFile$ and initializes the stepper motor drives.

StepMotorStatus
Displays the content of the PhytronIniFile$ on screen.

SwitchStatus
Displays the status of the limit switches and the status of sensor switches of the
vacuum/pressure supply for the z-axis granite bench.

VacuumStatus
Checks the status of the sensor switches of the vacuum/pressure supply and
displays a red message on the screen if not ready. Remember that these switches
are interlocked with the COMPUMOTOR drive.

SCAN: Contains the SCAN subroutine, which performs a preselected scan.

Scan
Performs a scan with selectable parameters. Scan direction is either x, y, or z
(later w). Offsets are a cyclic permutation of direction. For example, if the scan
direction is x, offset1 is y, offset2 is z, and offset3 is w (not used presently). Scan
takes care of all actions necessary to perform a scan, such as moving to the
appropriate start position, adjusting the desired speed, proper HP3458A setup if
ACPCinUse% = 1,2,3 or if the Walker integrator is used (IntegratorDriftKorr%=1,
true). It adjusts the drift of the integrator to zero and performs an offset field
measurement at the beginning of a scan if OffsetKorrNr% > 0. This number
affects the number of offset measurements to be taken only if ACPCinUse% = -1
or 0. If ACPCinUse% =1, 2, or 3, a high resolution measurement is taken using
the HP3458A. Both on-the-fly (OntheFly% =-1, true) or point-by-point
measurements can be done using SCAN. However, using the point-by-point

mode, only ACPCinUse% = -1 is possible (see STARTUP description). In on-the-fly mode, the scan is performed depending on the measurement mode used. In any case, the ACURITE system is read out at a rate of approximately 100 Hz during the scan. If a reading falls within a window that has previously been defined according to step size and speed, a measurement is taken using subroutine DAS8MESSUNG. It will be the final measurement if ACPCinUse% = -1 or 0. Note that the step size of these measurements will not be equidistant. Due to the nature of the method, there is some jitter around the nominal step size. Each measurement is stored in fast binary mode on a virtual diskfile. The limiting factor for the number of possible measurements is the size of the virtual memory. A computer screen graph of the field together with the first and second field integrals is made if curves 2 and 3 have been enabled (see MONIPLOT description). Remember, DAS8MESSUNG performs a Hall probe linearization if selected. If ACPCinUse% =1,2,3, the HP3458A works in fast digitizing mode, and measurements are triggered directly by the ACURITE glasscale (see HP3458ST module description). In that case, the HP3458A is stopped after the measurement. The number of actually performed readings is read out and compared to the expected one according to the formula

 Expected # of readings = (Endpoint - Startpoint) / Stepsize - 1.

Under normal conditions, this number should always coincide with the actual reading. An error code is generated if the deviation is larger than 1. The memory of the HP3458A is read using the subroutine HP3458STORE, and the data on the virtual disk file is replaced by the linearized (if desired) data of the HP3458A. After the scan, the results (the end parameter field, the first and second field integrals) are sent to the lineprinter, Resultmarker%=1. A protocol is also printed on page 1 of the display and can later be recalled by switching from page 0. In point-by-point mode, the whole measurement is much simpler. You move to each point using absolute positioning mode with the maximum accuracy of the ACURITE system (+/-.005 mm in x and y and +/-.0025 mm in z). A measurement is taken using the HP3458A, displayed, and stored on virtual disk. In this mode, one data point takes about 3 to 4 seconds. An emergency stop, by pressing a character, is possible during every movement of the bench and while the memory of the HP3458A is read out and displayed. The character pressed is used to control further action in subsequent subroutines. During SCAN, an error code is generated to inform the user about errors encountered.
SCAN Errorcode% :
    < 0   no measurements were made. Scan stopped immediately
     0   scan performed with input parameter OK.
     1 - 3   full scan but with reduced speed
     4,5   partial measurement
     6 - 9   errors related to HP3458A digitizer mode ACPCinUse%=1,2,3.
If the number of errors is > 0, then the first will be shifted one digit to the left. For example, Error 28 means that the first error encountered was error 2, followed by error 8. Errors < 0 are lethal errors leading to immediate suspension of the scan.

SCAN error codes in detail

-6 :   number of estimated datapoints too large for HP3458A. This means (for DESY) (ScanEnde - ScanAnfang)/Delta>=37888. Only HP3458A digitizer modes d. h. ACPCinUse%>=1: no measurement

-5 :   illegal direction, neither x, y, z, nor w: no measurement

-4 :   delta is zero or negative: no measurement

-3 :   start and endpoint too close: no measurement

-2 :   emergency stop while searching startposition or during integrator drift adjust: no measurement

-1 :   delta, messrate, and speedmin incompatible even for the minimum possible speed, delta is still too small. Take larger stepsize: no measurement

0 :   measurement OK

1 :   speed was < speedmin and was increased: full measurement

2 :   speed was > speedmax and was decreased: full measurement

3 :   speed has been decreased because the step width was too small: full measurement

4 :   stop by NSTOP, identical coordinate readings (normally no movement of the bench): partial measurement

5 :   emergency stop during scan: partial measurement

6 :   step width delta has been changed for one of the following reasons: only HP3458A digitizer mode, ACPCinUse% >= 1

7 :   HP3458 digitizer mode d. h. ACPCinUse% >= 1: step size for control measurement using DAS8MESSUNG on Channel1 has been increased. Has no effect on data taken by HP3458A: full measurement

8 :   the actual number of data points deviates from the predicated number of points by 1 or more points (only if ACPCinUse% >=1): measurement may be erroneous

9 :   the max. possible measurement rate (about 500/sec) is too small for the selected Vscan and Delta values, i.e. Vscan/Delta >= 500Hz, Vscan has been reduced. ACPCinUse% >=1 only: full measurement

----

SETCOLOR: Contains subroutine SETCOLOURS

Setcolours
Used to change the colors of the curves, the frame, the background, and the scaling. It changes the COMMON SHARED variables :

FarbeHinterGrund%   (Background color)
FarbeRand%   (Color of Frame)
FarbeKurve1%   (Color of Curve 1)
FarbeKurve2%   (Color of Curve 2)
FarbeKurve3%   (Color of Curve 3)
for display color and
Ydisplaymin1   YdisplayMax1
Ydisplaymin2   YdisplayMax2
Ydisplaymin3   YdisplayMax3

for display scaling. If the display of one curve is not desired, set the color to -1.
Called in the subroutine STARTUP.

SETPRINT: Subroutines to setup the HP Laserjet printer and to read out the
printer status register.

MessageBox
Displays a red bar with a text string to displays messages.

Printercheck
Calls the subroutine PRINTERSTATUS and generates the message for the
subroutine MESSAGEBOX.

PrinterStatus
Reads out the printer status register. PRINTERSTATUS is not executed if the
printer status address is set to zero in the BUSADRESSFILE$.

SetPrinter
Sets the textsize on the HP Laserjet printer.

SPLINE: Spline interpolation for Hall probe linearization.

HUNT
Fast search for array elements, it is needed by SPLINT.

SPLINE
Calculates spline coefficients from a tabulated function.

SPLINT
Interpolates tabulated function values using spline interpolation. SPLINE must
have been called prior to this subroutine, it needs HUNT.

STARTUP: Controls the STARTUP procedure at the beginning of the program and
when choosing the "Run STARTUP again'" item in the menu.

CTMtimer
Exactly measures the time between two calls using the CTM05 timer board.

HallProbeOffsetKorrection
Used to correct for unavoidable drift of a Hall probe system. Normally Hall probe
systems allow for adjustment of the zero reading in zero magnetic field. It is done
by putting the Hall sensor into a zero Gauss chamber and adjusting the output
with a screw potentiometer. Our system, the Group 3 HPI, does not have a zero
adjust. In our case, one has to measure the offset separately and subtract from
each measurement. This subroutine measures the Hall probe output voltage
when the probe is in a zero Gauss chamber and places the result in the
COMMON SHARED variable, HALLPROBEOFFSET. This value is subtracted

in every measurement using DAS8MESS. Offset is also corrected for when reading out the memory of the HP3458A in the HP3458STORE subroutine.

MessParameter
This subroutine allows for setting a number of bench control variable parameters in the COMMON SHARED block during the STARTUP procedure. It is similiar to the subroutine MAPPARAMETER. The parameters can be displayed, changed, and stored on a disk. New parameters can be read from the disk. In MESSPARAMETER, only those variables that affect the overall performance of the bench, like bus addresses, measurement mode, instrument range, display scaling, etc. can be changed. Parameters needed for a particular measurement have to be changed using the subroutine MAPPARAMETER. The following COMMON SHARED variables can be manipulated by this procedure:

Busadressfile$	file with bus addresses
PhytronIniFile$	file for stepping motor initialization
HallprobeFilename$	file for linearization data for Hall probe
ACPCinUse%	measurement mode for the bench
OntheFly%	if true (-1), on-the-fly, otherwise, point-by-point measurement
IntegratorDriftKorr%	drift correction Walker integrator if true (-1), switched on
ACPCresolution%	not used at APS
Channel0inUse%	1 if selected, 0 if not
Channel1inUse%	1 if selected, 0 if not
Channel2inUse%	1 if selected, 0 if not
ACPCdelaytime	not used at APS
ACPCconversionChannel0	not used at APS
ACPCconversionChannel1	not used at APS
ACPCconversionChannel2	not used at APS
FullscaleX	full scale range x in kG
FullscaleY	full scale range y in kG
FullscaleZ	full scale range z in kG
AusgangX	full scale voltage x
AusgangY	full scale voltage y
AusgangZ	full scale voltage z
HallprobeLinearitycontrol%	linearity correction on if = 1
FarbeHinterGrund%	graphics: background color
FarbeRand%	color of frame
FarbeKurve1%	color of curve 1
FarbeKurve2%	color of curve 2
FarbeKurve3%	color of curve 3
Ydisplaymin1, YdisplayMax1	plot limits for curve 1
Ydisplaymin2, YdisplayMax2	plot limits for curve 2
Ydisplaymin3, YdisplayMax3	plot limits for curve 3

Some variables are not needed at APS. Channels 0 and 1 can be used, but only on the DAS8PGA board using ACPCinUse% = 0. Currently, there is no wiring.

PrintMessParaMeter
Screen display for subroutine MESSPARAMETER

ReadHallprobeKorrektur
Reads the HallprobeFilename$ if HallProbeLinearitycontrol%=1. If SPLINE data
are read in with the string "SPLINE" as the first six characters in the first line of
the file, it reads in the calibration measurement values "Hallprobefield" in Gauss
and "true field", from the NMR probe, in Tesla. It calculates and corrects the
Hall probe field in kiloGauss and the correction to the field to obtain the true field
in Gauss. True field and Hall probe field are related through the equation:

true B in kG = B measured in kG - Correction in G / 1000.

The results are placed in the COMMON SHARED arrays HallProbeField() and
HallDeviation(). Spline coefficients are calculated and placed in the COMMON
SHARED array, HallProbeSplineKoeff() using the subroutine SPLINE, for later
spline interpolation using the HALLKORR'function. If data for polynomial
approximation is read, the first six characters of the first line must read
"POLYNO." Then polynomial coefficients for an approximation of the correction
to the measured Hall probe field are read in. The function "HALLKORR"
recognizes which correction method is chosen. If neither "SPLINE" nor POLYNO
are the first characters of the HallProbeFileName$, an error is generated and
HallProbeLinearityControl% is set to 0.

COMMON SHARED variables that may be changed by this subroutine:
HallprobeLinearitycontrol%   linearity correction on if = 1
HallProbeKorrdate$ string containing date of last calibration
HallProbeType$ string containing type of Hall probe
HallProbeSerialNo$ string containing Hall probe serial number
HallprobeMinfeld   lower limit of calibration range
HallprobeMaxfeld   upper limit of calibration range
HallprobeKoeff()   array with polynomial coefficients   ###
HallprobeLinearityType$ if "S," the splines; if "P," the polynom
HallProbeSplineNr%   number of data points for spline treatment $$$
HallDeviation()   correction to Hall field $$$
HallProbeField()   measured Hallfield $$$
HallProbeSplinKoeff()   spline coefficients for interpolation $$$
                                  $$$, if splines are active
                                  ###, if polynoms are active

Startup
Controls the entire startup procedure.
        1. calls MESSPARAMETER to obtain valid parameters
        2. calls DEFADD to define addresses
        3. calls STEPMOTORSINI to initialize stepping motors
        4. sets the HP3458A in the proper mode using ACPCinUse% and OntheFly%
        5. sets up the Keithley 195A voltmeter
        6. measures the time it takes for one call to DAS8MESS and stores it in the
          COMMON SHARED variable DeltatMessOnly.

WRIDISK: Contains the subroutine 'STOREONDISK' which writes measured data on a disk.

   StoreOnDisk
   Controls and manages data storage on diskfiles. It reads out the virtual memory and writes the data on disk according to the following rules:
         - field maps measured on-the-fly with modes ACPCinUse% = 1,2,3 (HP
     digitizer modes) are stored in binary format without coordinate values
because they have to be reconstructed anyway,
         - field maps measured point-by-point or with ACPCinUse% = -1 or 0
           are stored in ASCII format with coordinate values. These spectra
           therefore require much more storage space,
         - if a field map has more than one scan, individual scans are appended one
     to the other,
         - field integrals are stored in ASCII format.

All data relevant for a measurement are stored. The format of this subroutine is such that data can easily be read by the data evaluation package AUSWERT.

ZERO: Subroutine for drift compensation of the Walker integrator by means of the stepping motor attached to it.

   HPmess
   Reads out the HP3458A.

   Nullset
   Controls the whole zero adjust procedure:
   1. adjusts the drift to zero,
   2. checks the display of the integrated flux and, if necessary, drifts it to zero by
      rotating the stepper motor one revolution in the appropriate direction and
      rotating it back one revolution when the display is approximately zero,
   3. checks drift again.

   WalkerMotor
   Used to control the movement of the motor to adjust the drift.

   Zero
   Closed loop program to adjust the drift of the Walker integrator to zero. The drift is measured and the adjustment angle is determined to adjust the drift to zero. The procedure is repeated until 10 successive measurements are made that are below a threshhold. The actual values are displayed. There is the possibility to interrupt zero adjustment by hitting the "H" key and continue zeroing by hand.

   ZeroMess
   Makes two measurements of the Walker integrator output in a well defined time interval to determine the drift.

Further subroutines referenced:

National Instruments NI-488.2 driver routines
IBDMA   RECEIVE
SENDIFC   SEND
DEVCLEAR
For further information see NI-488.2 MS-DOS Software Reference Manual.

Utility programs from the QBX Add-On-Library
FormatI$
FormatS$
See Add-On-Library documentation page 433ff of Microsoft BASIC

Menu ToolBox
See MENU ToolBox documentation page 536 ff of Microsoft BASIC
MenuCheck   MenuPreprocess
MenuColor   MenuSet
MenuInit   MenuShow
MenuOn   ShortCutKeySet
MenuOff

See MOUSE ToolBox documentation page 581 ff of Microsoft BASIC
MouseHide
MouseShow

See WINDOW ToolBox documentation page 550 ff of Microsoft BASIC
ButtonClose   WindowDo
ButtonOpen   WindowInit
ButtonSetState   WindowLocate
EditFieldClose   WindowOpen
EditFieldOpen   WindowPrint
WindowClose   WindowSetCurrent

This is the HELP File for the data evaluation program. All program action is controlled by command. Some commands may have additional parameters denoted by #1, #2, #3, etc., depending on the number. Additional parameters must be separated by commas or spaces. If you omit the parameters, there will always be a default action. In many cases, if no parameters are specified, you will be queried. All commands can be found in the Help file. Specific help on a command can be found by HELP and the command, for example, "HELP NEW" will explain the NEW command. Many commands can be abbreviated using only the capital letters.

BASIC Operation: There are two internal buffers in to which data can be read using the NEW command. "NEW 1 test1.dat" reads the file "test1.dat" into Buffer1. "NEW 2 test2.dat" does the same with file "test2.dat." There are severe restrictions on the file formats. Generally, each file generated with the BENCH program should be readable with these commands. There are commands like "subtraction of two spectra" which need the spectra stored in these buffers. The resulting spectrum will then be displayed in the display buffer. The BER command will copy a buffer back into the display buffer. BER1 will copy Buffer1 into the display, buffer BER2 will do the same with Buffer2. There is another set of commands using only one operand spectrum like differentiation, integration, Fourier transform etc. These operations use the display buffer and subsequently overwrite it. There is no operation changing the contents of the buffers. To provide enough memory for the buffers, a parameter is specified when calling the program. For example, AUSWERT 4000 will provide storage for 4000 datapoints. However, redimensioning will occur when trying to read larger spectra, but only as far as the memory limits of the computer allow. Memory limits depend on the number of drivers and memory resident programs installed. Currently, data sets with up to 10000 datapoints can be processed. Even larger ones can be used when avoiding commands that require additional memory like FOURIER transforms, cursor activation, or subtraction of spectra.

BASIC INPUT:

COMMAND: parameter separated by blanks or commas
Examples:
  SUM   gives command summary
  HELP FOU   gives help on the FOU command
  NEW or NEW,1   read new file in Buffer 1; 1 is default
  NEW 2 or NEW,2   same as above, except with Buffer 2
  FOU,,,LOG   fast Fourier transform (FFT) of absolute value (default)
                      in logarithmic representation; commas are required
              because arguments are skipped
  FOU   FFT as above (default values only), linear representation
  FOU,R,L or FOU R L   FFT real part (cosine coefficients), output on
                      line printer (not recommended, uses too much paper!)

COMMAND Description
COMMAND SUMMARY

EXit	exit program	HPIni	initialization
NR	set number of scan to be read	HPend	end plot
SCale	scaling	HPLot	plot spectrum
AUS	select area for plotting	HPKopf	write header
DIF	differentiation	FArbe	select color
INT	integration	LT	select linetype
+*:	addition, multiplication, division	SYMbol	plot symbol instead of lines
SQuare	square	HPWrite	write text into plot
DR	show header and data	HPFile	redirect plot output
PRF	redirect printer output	Laplo	plot HP file on HP plotter
NEW	read new spectrum into buffer	SUM	command summary
SPAlten	select column number	RMS	root mean square, mean value
BER	copy buffer into display		
RE	reorder		**Commandfile Commands**
WErt	interpolated value (WERT)		COM; starts commandfile
SIMP	simpson integration		BAck; commandfile end
SUB	subtraction of spectra		STop; stop commandfile
SS	shift spectra for subtraction of spectra		RESume; resume commandfile mode
Y2F	input factor for subtraction of spectra		
SX	shift spectrum in x		
USUB	noise level subtraction		**Data processing for Lamda Coil**
WRite	write spectrum on disk		SM1; lamda coil simple
NPLot	plot only each nth point		SMT; lamda coil interlated
REMark	comment on display or printer		
AF	analytic field		
MM	search maxima and minima		**Fourier transformation**
CU	call cursor		FOU; fast Fourier transform (FFT)
HElp	help		WIN; window function for FFT
SYstem	push to DOS		FOUP; output absolute value of max.

STAtus after reading a file
- : -5   interrupted by EXIT command
- : -4   Arraydim% < Count&, not enough memory for data arrays
- : -3   no filename defined
- : -2   ScanNr > als MaxScanNr if known. (SatzNr, MaxSatznr)
- : -1   ScanNr = 0
- : 0   EOF not reached, can read another scan
- : 1   EOF reached, cannot read another scan

EXit   end program

NR #1,#2   select number of scan if several scans are stored in one file,
   #1 :   start number of scan
   #2 :   end number. If blank, you will be queried.

SCale,#1,#2,   scaling of graphics for display and HP plotter. If blank, you will be
#3,#4,#5   queried.
                  #1 :   A : autoscale
                         F : fixed then
                         #2 : Ymin
                         #3 : Ymax
                         #4 : Xmin
                         #5 : Xmax

AUS   cut out those points in the display array, the x-coordinates of which
                  are within the XMIN-XMAX boundaries, set by the SCale
                  command. AUS may be used to significantly reduce the number of
                  data points which are outside the plotting limits, sent to a plotter.
                  AUS acts on the graphics display and HP plotter.

DIF, #1   differentiate spectrum in display buffer
                  #1 :   Y   yes, do it
                  N   no, don't do it (default).

INT, #1   integrate spectrum in display buffer
                  #1 :   N no, don't do it (default)
                         1   integrate once (for first field integral)
                  2   integrate twice (for second field integral).

+ , #1   add a number to the spectrum in the display buffer; to subtract,
                  add a negative number.
                  #1 :   number to be added.

* , #1   multiply number to the spectrum in the display buffer.
                  #1 :   number to be multiplied to spectrum.

: , #1   divide spectrum in display array.
                  #1 :   number.

SQuare ,#1   square spectrum in display buffer.
                  #1 :   Y   yes, do it
                  N   no, don't do it (default).

DR, #1   print last scan read onto screen.
                  #1 :   1 header only
                  2 data points in addition (a lot of numbers).

NEW,#1,#2,#3   read new file into buffer.
                  #1 :   1 into buffer 1 (default)
                  2 into buffer 2
                  #2 :   filename
                  #3 :   column number is optional if a file containing data stored in
                  several columns, such as field integral scans, is read. Only

values 1, 2, or 3 make sense. See the SPAlt command. If 3 is blank and there is more than 1 column, you will be queried.

SPAltennr,#1 column number only for files containing more than one column (field integral scans). Only values of 1, 2, and 3.
     #1 : column number. If empty, you will be queried.

BER,#2 copy data from buffer 1 or 2 into display buffer.
     #1 : 1 buffer 1 (default)
       2 buffer 2.

RE   reorder x-values of display buffer to inclining order.

WErt ,#1 ,#2 calculate interpolated value (WERT) of the spectrum in the display buffer using spline interpolation.
     #1 : value on which the function is to be determined must be within the values of the spectra displayed
     #2 : if "P", output to line printer.

PRFile ,#1 redirect printer output.
     #1 : "DEF" default device, normally LPT1:"PRN" lineprinter.
     <u>Caution</u>, old files are overwritten. Checks for valid file names are not made. Using the HP laser jet plotter directly (LPT1:) may cause conflicts and meaningless output if mixed up with normal printer output. If #1 is blank, you will be queried.

REMark,#1,#2 display parameter #1 as comment. Using REM, operational hints such as "change paper " can be displayed and the program halted. Comment can be given on printer outputs.
     #1 : string of characters (no blanks or commas) to be displayed
     #2 : If "P", output to line printer, otherwise on display and wait for a key stroke to continue.

SIMP,#1 Simpson integration and error estimate over the entire plotted part of the display buffer. Using this command, the error of the simple trapezoidal integration used in the INT command is estimated. Use SCALE and AUS to change the integration range.
     #1 : If "P", output to line printer.

SUB,#1,#2,#3 Subtracts interpolated spectrum in buffer 1 from buffer 2.
     #1: Y, do it (default)
       N, don't do it. N also frees memory for spline coefficients. If previously used, it may give additional storage in the display buffer for large spectra.   A previous use of SS will shift the spectra; a previous use of Y2F will multiply the second spectrum by that factor. See SS and Y2F commands.
     #2: If "XY", the y-values of buffer 1are stored in the display array x and the y-values of buffer 2 (in case interpolated), are stored in the display array y

hence: X corresponds to Y1, and Y corresponds to Y2
#3:   If "HALL", the y-values of buffer 1 will be subtracted from
buffer 2 and stored in the display array y
hence: X corresponds to Y1, and Y corresponds to Y2 - Y1.

SS #1   shift spectrum: the two spectra to be subtracted are shifted relative
to each other. A positive value shifts buffer 1 to larger values. SS
alone has no effect. Always perform SUB after SS.
#1 :   shift value. If blank, you will be queried

Y2F #1   scalings factor of buffer 2 for subtraction. Like SS, Y2F has an
effect only after the SUB command.
#1 :   scaling factor: input -1 if you want to add two spectra. If
blank, you will be queried.

SX,#1   shift X: add #1 to the x-coordinate values in the display buffer.
#1 :   shift value. If blank, you will be queried.

SMT,#1,#2,#3   deconvolution/evaluation of lamda coil measurements and
reconstruction of the first field integral. Interpolation method.
Very time consuming!
#1 :   length of coil in millimeters, it need not be a multiple of the
stepwidth used in the scan.
#2 :   width of coil in millimeters
#3 :   # of windings.

SM1,#1,#2,#3   deconvolution/evaluation of lamda coil measurements and
reconstruction of the first field integral. Fast and simple method.
#1 :   length of coil in millimeters. It must be a multiple of the
step width used in the scan.
#2 :   width of the coil in millimeters
#3 :   # of windings.

USUB   noise level subtraction. The noise level is defined by the average of
two points that can be enclosed in the cursor mode (will be CU) by
the f1 and f2 keys.

RMS ,#1   root mean square and mean values of all data in the working
window are calculated. May be limited using AUS command.
#1 :   "P", print results on line printer, otherwise on screen.

WRite,#1   write display buffer as a ASCII file to disk.
#1 :   filename.

NPlot,#1   plot only each Nth data point on display or HP plotter.
#1 :   N. If blank you will be queried.

FOU,#1,#2,#3   fast Fourier transform (FFT) of the display buffer.
#1 :   R   real part (cosine)

A3-5

I   imaginary part (sine coefficients)
                            else   absolute value - FFT
                    #2 :   D   print FFT onto screen, a lot of output!
                    L   print FFT onto line printer, a lot of paper!
                    else   print nothing
                    #3 :   LOG   logarithmic representation of the Fourier
                                coefficients, otherwise linear representation.

FOUP ,#1   outputs the absolute value of the maximum in a Fourier-spectrum
                because absolute values are always normalized to 1.
                #1 : if = "P", output to line printer.

WIN ,#1   defines the windowing function used for the FFT as start and end
                point for the data to be windowed. The plotted range as selected
                with SCALE and cut with the AUS command is taken. WIN acts
                on the display buffer only.
                #1 :   "D"   triangular window " Parzen Window " "Dreieck"
                   :   "C"   cosine window " Hanning Window "
                   :   else   rectangular.

AF,#1,#2   analytic array (field) calculated from user supplied Fourier
                coefficients. They are stored with other data in the file
                "AUSWERT.HAR." There are also explanations for the input. AF
                is a good way to test the Fourier transformation routines.
                #1 :   D data output and change possibility on the display.
                L only lineprinter output
                #2 :   S the calculated array is stored as file TEST.FOU. You
                   can read it again with the NEW command.

MM,#1,#2   search for maxima, minima, zero crossing, etc. in display buffer.
                #1 :   threshhold value for maxima and minima search. Maxima
                and minima below the threshold are noise. Default is .005 T.
                #2 :   Minimum slope modulus if a zero crossing is to be counted
                as a zero crossing (noise). Default is .005T/mm.

CU   activates the graphics cursor. A yellow cursor appears and the
                spline interpolated function values are displayed on the bottom
                line. Any x-value between the data points will be displayed.
                Operation: arrow right, left; moves cursor right, left
                                arrow up, down; speeds cursor speed up or down
                                'E'; ends cursor operation
                                any other key stops cursor.

HElp ,#1 ,#2   activates help utility.
                #1 :   obtain help on a specific command, otherwise output the
                whole help file
                #2 :   L, print on line printer, otherwise display (default).

SYstem   push to DOS, to return from DOS, type "EXIT."

SUM ,#1   give command summary.
                 #1 :   L,   output on line printer, otherwise display (default).

Special HP Plot Commands

HPIni   initialization of the HP7475 plotter, normally not needed.

HPFile,#1   redirects the HP graphics plotter output.
                 #1 :   DEF   default plot file : HP7475.PLT
                        LAS , LASER   directly to HP laser jet plotter
                        Filename   plot file name
                 Query if #1 is blank. <u>Caution</u>, direct output to the HP laser jet
                 plotter conflicts with normal printer output.

LAPLO ,#1   output an existing HP graphics plot file on the HP laser jet.
                 #1:   file name; If blank, the last plot file name will be used if
                 the plot has been closed with HPE, otherwise no action.

HPend   ends a HP plot, and closes the plot file. Required if multiple plots
                 are to be made or plot files are plotted using the LAPLO command.
                 All plots are automatically finished on exit.

HPLot,#1   HP plots the display buffer. Scaling as on the screen is used (use
                 SCALE Command to change it). HP plot will be initialized.
                 #1 :   A :   plot data and axis
                        N :   plot data only
                        else :   you will be queried
                 The actual plot occurs only after input of one blank line.

HPKopf   plots a header.

HPWrite,#1   writes the text contained in #1 beside the plot. Text must not
                 contain commas or blanks (see REM command).
                 #1 :   text to be written. If blank, you will be queried. If queried,
                          you may also HPWrite blanks and commas.

FArbe,#1   set color on HP pen-plotters, initialize if necessary.
                 #1 :   pen number. If blank, you will be queried.

LT,#1   set line type, initialize if necessary.
                 #1   line type corresponds to HP7475 handbook. If blank, you
                 will be queried.
                     <0 oder >6   full
                     0 ,DO, DOT   dot
                     1 ,DODO,DOTDOT   dot dot
                     2 ,DA,DASH   dash short
                     3   dash long
                     4 ,DODA, DOTDASH   dash long dot

<table>
<tr><td>5</td><td>dash long dash short</td></tr>
<tr><td>6</td><td>dash between dash long dash short.</td></tr>
</table>

SYMbol,#1,#2   symbol mode. Plots centered symbols instead of lines. Any SYMbol command activates SYMBOL Mode. To switch it off, use "SYMbol Off " and plot lines again.
#1 :   number of available symbols: (if blank, you will be queried).

1 :	triangle up	8 :	square
2 :	triangle down	9 :	square with cross
3 :	upright cross	10 :	star with six corners
4 :	skew cross	11 :	circle
5 :	radiating star	12 :	circle with upright cross
6 :	diamond	13 :	circle with star
	7 : diamond with cross	else :	circle with skew cross.

#2 : symbol size in millimeter. If blank, you will be queried,

Special Commands for Commandfile Mode

COMmandfile,#1 command transfer to command file or to new command file. These files can contain all commands in a one line format, e.g.:

      NEW,1,Test.dat
      SC,F,-1.5,1.5,-300.,300

The single arguments are separated by blanks or commas:

      SC f -1.5 1.5 -300 300

#1: Name of the command file. If no name is entered, the default name is COMFILE.DAT. You can also call this command regressively. It is part of a command file, so the control is transferred to the new command file. When this is finished (file end), there is a jump back to the preceding or into the command mode. This putting in boxes is only possible two levels deep. It allows the call of often used subroutines. If you try to go deeper than two levels, the control is transferred to the new command file without having a jump back. The command file mode is very useful for the repeated entry of the scale factors,plotting, etc.

BAck, #1   leaves the command procedure. It applies only to the command file. The command file is closed and control is keyboard activated.
#1:   If "B," will be a step back of one command file level, otherwise the command file code is exited.

REsume, #1   continues the execution at the interrupt.
#1: If reset, sets back the line counts, no execution.

STop   command file command STOP.   Allows one to interrupt the execution of a command file or to finish, e.g., to put new paper in the plotter and continue after pressing a key. Input "E" leaves the command file mode and another key continues.